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General Technical
Report RM-218

Ecology and Management of Oal
and Associated Woodlands

Perspectives in the Southwestern Unitec
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April 27-30, 199
Sierra Vista, Arizor

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This symposium focused on technologies that bridge the gap between research and its application in the management of woodlands. Topic areas include: ecology and silvicultural practices; growth, yield, and utilization potentials; livestock and grazing practices; wildlife habitat and values; and hydrology and watershed management. The proceedings include titles and abstracts of all papers in Spanish, a bibliography, and a summary of research needs.

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General Technical Report RM-218

August, 1992

Ecology and Management of Oak and Associated Woodlands:

Perspectives in the Southwestern United States and Northern Mexico

April 27-30, 1992
Sierra Vista, Arizona

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Symposium Sponsors:

Rocky Mountain Forest and Range Experiment Station
and
Southwestern Region,
Forest Service, U.S. Department of Agriculture

School of Renewable Natural Resources
The University of Arizona

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Foreword

The purpose of this symposium was to examine the current knowledge on the ecology and management of oak and associated woodlands, with perspectives presented from the southwestern United States and northern Mexico. Research to improve management of multiple-use values of encinal woodlands was a primary focus of the symposium. In addition to the encinal woodlands, pinyon-juniper and Gambel oak woodlands in the southwestern United States were considered, along with oak woodlands in the Sierra Madre of northern Mexico and pine-oak woodlands of Baja California Sur, Mexico.

Invited papers summarized the research knowledge and management experience on ecology and silvicultural practices; growth, yield, and utilization potentials; livestock and grazing practices; wildlife habitats and values; and hydrology and watershed management in the woodland communities. Volunteer poster papers described the results of research and case studies, and presented management practices for multiple-use values. Technologies that bridge the gap between research and its application in the management of woodlands was emphasized. Opportunities for developing and applying predictive models as management tools also were examined. To conclude the symposium, a discussion of research and management needs in the woodland communities was held, a summary of which is presented in this proceedings.

The symposium consisted of two days of technical sessions involving presentations and subsequent discussions of the invited papers, and a one-day field trip to view on-site management activities in the encinal woodlands of southeastern Arizona for multiple-use benefits. Scheduled sessions for poster displays allowed time for discussions with the presenters.

Invited papers and volunteer poster papers presented at the symposium are published in this proceedings. To ensure quality, each of these papers was reviewed by at least two reviewers. People who served as reviewers are thanked by both the organizers of the symposium and the respective authors. Opinions expressed in these papers are those of the authors, and do not necessarily reflect opinions or positions of the sponsoring organizations.

Opening Remarks

H. M. Montrey, Director,
Rocky Mountain Forest and Range Experiment Station
USDA Forest Service, Fort Collins, CO

It is a pleasure to be able to participate in this symposium and help address the ecology and management of oak and associated woodlands. This meeting reflects the growing interest in the United States and Mexico, and indeed the entire world, in management of arid woodland ecosystems. As you know, most previous forest land management and research efforts have been directed towards questions concerning the "commercial" timber types. But now, there is a growing interest in multiresource management as well, of the arid woodlands for sustained ecosystem health and productivity. For instance, the last decade has seen surging interest in the ecology and enlightened management of the pinyon-juniper ecosystem. I view today's symposium as a welcome continuation of this process.

Why the interest in these arid woodland ecosystems? (1) One obvious reason is the sheer size of land area in the western United States and northern Mexico containing these cover types. For example, the evergreen woodlands or oak woodlands, which are of primary interest to these proceedings, cover approximately 80,317 sq. km in the southwestern United States and northern Mexico (Ffolliott 1989). Although much of this vegetation occurs in the Sierra Madre Occidental of Mexico, it is an important vegetation type in southeastern Arizona, southwestern New Mexico, and in areas of Texas. Also, the pinyon-juniper woodlands cover approximately 190,206 sq. km. in the western United States (Evans 1988). Pinyon-juniper, juniper, oak and other arid woodlands cover large areas of Arizona, making up 72 percent of the forested land (Conner et al. 1990). Moreover, Gambel oak dominates woodlands in many areas of the West or is an important component of the ponderosa pine forest. Similar woodlands also are common in other arid regions throughout the world.

(2) Another reason for interest is arid ecosystems are very sensitive to the natural variability of the climate and to the impacts of human activities. They recover very slowly after disturbances because of low precipitation and poor soil nutrient levels. There is little room for error in use and management if productivity of the land's numerous plant and animal resources are to be sustained. In our own and in many other areas of the world, this sensitivity has a direct impact on the health and well-being of the human populations.

(3) The growing populations in the Southwest have increased existing and added new demands on the woodlands. Many new uses are perceived to be in conflict with traditional land management objectives. Outdoor recreational needs have placed a strain on the economic resources of land management agencies and, in places, on the ecosystems they are stewards for. To further complicate matters, the management of these woodlands must increasingly consider the unique mixes of plants and animals they house. Mixes are not found in other regions of the United States. The presence of large numbers of neotropical birds and other Mexican and tropical species provides opportunities for recreational bird watching and for a wide array of ecological studies. Management's challenge is to insure suitable habitat for the unique and common wildlife and plant species while continuing to satisfy other concerns. Tough job!

State of knowledge/Urgency of interest

Unfortunately, our knowledge to relate the basic ecology to the breadth of integrated resource management experiences for the oak and associated woodlands is incomplete. Management decisions should take maximum advantage of sound scientific information that exists and managers should identify needed gaps in scientific information. Meetings, such as this one, present resource managers from public and private organizations as well as researchers with opportunities for the exchange of information and ideas. This symposium should provide a forum where questions and concerns can be raised and discussed, and where potential answers can be developed. My hope is that we all clarify the gaps in our knowledge and see more clearly directions for our future efforts. The presence of a contingent of managers and scientists from Mexico, and from the United States, provides us all with many perspectives on woodland ecology and management. We should all take advantage of the setting. We also should recognize that our discussions here in Sierra Vista can have implications for the wise management of similar woodland ecosystems throughout the world. The proceedings that will result from your activities will serve as a vehicle for technology exchange and as the basis for future research. I wish you success in developing a program to help improve management of the important oak and associated woodlands for multiple use values.

Forrest Carpenter, Deputy Regional Forester
Southwestern Region, USDA Forest Service, Albuquerque, NM

It's a pleasure to be with you this afternoon. The title of Today's symposium highlights our recognition that ecology and management of oak and associated woodlands are important vegetative communities in the southwestern United States and northern Mexico.

I want to thank the organizers of this symposium and I am impressed by the list of topics and persons presenting papers this week. It's good to see such a large attendance, especially our friends from Mexico, both from the private and public sectors.

Benefits from the oak community are enormous. We care for this ecosystem and recognize many values, such as recreational use – birding, hiking, camping, and viewing scenery.

The oak community is excellent habitat for many animals and neotropical birds and a wide variety of plant and animal species. It also provides fuelwood, forage for livestock grazing, and such products as jojoba beans and beargrass. And these are only a few of the benefits it provides!

Given these many different values and uses of the oak community, there will be conflicts between uses – for example, between grazing, fuelwood gathering, recreation, and keeping a diverse habitat for the many wildlife, bird, and plant species in this highly sensitive vegetative community.

This meeting gives us a chance to better define those conflicts and work toward a common solution and knowledge base for oak ecosystem management.

This meeting also provides an opportunity for researchers, managers, public agencies, and private landowners to share what we know about the oak community – a community that extends well into Mexico, southern California, and, of course, in southwestern New Mexico and southern Arizona.

At a time when we in the Forest Service are beginning to practice ecosystem management, it becomes more important that we share our knowledge with one another. An ecosystem management approach requires a greater sharing of knowledge to develop an understanding of how the oak plant and animal community works together and to learn how humans play a major role in that community.

I'll spend a little time here discussing ecosystem management because we in the Forest Service think that's our future direction in the stewardship we must practice in our plant and animal communities. We are learning as we go and are excited by what we think is the management of the future, where humans and plant and animal communities function harmoniously.

The points that I would like to make with ecosystem management are these:

First, we must refocus our efforts on building an ecosystem approach to natural resource management. In other words, multiple-use management must be ecology-based. That's a new concept and the current emphasis of the Forest Service. That's not the way we managed in the past and that wasn't wrong. But now we recognize there is a better way to work with nature.

Second, ecology-based multiple-use management must be built in partnership and trust among resource managers, scientists, and people affected by how forests, woodlands, rangelands, and riparian areas are managed. Ecology-based multiple use is largely a technical problem, but its implementation depends on social acceptance and understanding by managers and interested people.

Our understanding of a functioning ecosystem, that interaction between a plant or animal organism and its environment, contains large gaps in knowledge. We must act using the best available research information on plant and animal relationships that can predict favorable results and known consequences of our management decisions.

We must rely on meetings like this one to help transfer current knowledge to managers, specialists, and the public. We must ask ourselves, what do we know now? We then must rely on scientists to search out the unknowns.

Third, we have an enormous challenge in building multiple-resource sustainability within the framework of ecosystem health, resilience, and function. We must not compromise our ability to meet future needs while providing benefits for present generations, such as I mentioned earlier.

The only way we can do that is to learn ecosystem management techniques. Learn how ecosystems work and then work within the capability of an ecosystem to produce the commodities we need now and are also providing in the future. No matter what the need – wood, forage, wildlife, recreation, cultural resources, or aesthetics – the commodities for resources must be viewed as components of the greater whole, a functioning, healthy, sustainable ecosystem.

Fourth, we must design across broad landscapes providing a variety of conditions of plant and animal communities to maintain sustainable ecological systems, broad-scale ecosystems, like the oak community, perpetuated with all of their component parts through time.

We must develop strategies to implement ecology-based resource management. We in the Forest Service have made a start and we challenge others to become involved as we continue to explore the new concepts of ecosystem management.

The challenge to you this week is to listen carefully to the presentations at this session and to see how ecosystem management can occur when humans and plant and animal communities are in harmony. We are given the stewardship responsibility of caring for the land. This symposium brings us one step closer to learning how to practice ecosystem management in the oak community.

Eugene G. Sander
Dean, College of Agriculture
University of Arizona, Tucson

President Manuel Pacheco regrets he was unable to attend this opening session, but with some critical budget reductions facing the University for the next 2-3 fiscal years, he and his budget people are right in the midst of reviewing and evaluating the budget reduction plans submitted by all organizational units of the University. I can tell you he is very supportive of cooperative efforts like this, and especially where we are attempting to enhance our technical information exchange and cooperation with our colleagues from Mexico. Thus, he sends his sincere wishes for a successful Symposium.

As Dean of the College of Agriculture, I am tremendously pleased that our School of Renewable Natural Resources, largely through the efforts of Dr. Pete Ffolliott, have gotten together with the Forest Service to sponsor this symposium. Because of the ever increasing public interest in multiple use of our renewable natural resources of the Southwest, which are vast – and in some cases quite fragile – this is a timely symposium. From the titles of the papers and poster presentations, you should have a good idea of the most important research needs facing you in your attempts to improve the management of multiple use values of oak and associated woodlands in the southwestern United States and northern Mexico by the close of this symposium. The published proceedings will be a valuable resource document in guiding your future research direction, and I commend you for your plans to have these proceedings available shortly after the close of this symposium.

Expectations of the general public from the much publicized Free Trade Agreement between the United States and Mexico are, I believe, generally high. Not too many people understand some of the complications in successfully implementing this Agreement. Thus, I compliment you on your choice of a topic for the keynote presentation, and I'm most interested myself in what Dr. Harry Ayer of our College of Agriculture has to say on this matter.

Let me add my best wishes to those of President Pacheco and the previous speakers for a most successful symposium.

Research and Management Needs in the Woodlands of the Southwestern United States and Northern Mexico[1]

Peter F. Ffolliott,[2] Gerald J. Gottfried,[3] Duane A. Bennett[4]

Abstract.–Three listings of research and management needs in the woodlands of the southwestern United States and northern Mexico are presented. The first two provide an historical perspective to current efforts within the woodlands; the third listing represents suggestions and recommendations made by the participants at this 1992 symposium. Topics in the present listing are grouped under several broadly defined headings, such as general ecology, tree regeneration, mast production, wildlife, fire, hydrology and watershed management, social concerns, inventory and monitoring, and management. These three listings, and particularly that offered by the present participants, should be helpful in establishing an agenda for research and management in the near future.

INTRODUCTION

This 1992 symposium on the ecology and management of oak and associated woodlands in the southwestern United States and northern Mexico uncovered a number of important gaps in our knowledge of these woodland communities. To the extent that these gaps are lessened through future research and educational efforts, land management practices can be better formulated to satisfy the needs of people in the region.

Three listings of research and management needs in these woodland communities are presented in this paper. The first two, one prepared for an agency of the United Nations (Ffolliott 1989, Salem 1988) and the other prepared as part of an earlier oak woodland workshop (Ffolliott and Hasbrouck 1988), represent previous efforts to identify research and management needs. They are included to provide a historical perspective to much of the work that was reported upon in the 1992 symposium. The third listing evolved in the closing session of this symposium, in which participants were asked to express their opinions as to future efforts that might be taken to alleviate perceived research and management needs. It is hoped that these three listings, collectively, will be helpful in formulating an agenda for research and management in the future.

FAO CONSULTATION

A review of the state of knowledge and experience in dryland forestry in the southwestern United States and northern Mexico was undertaken as part of an international consultation on the role of forestry in combating desertification in the world (Ffolliott 1989, Salem 1988). Organized and sponsored by the Food and Agriculture Organization (FAO) of the United Nations as a satellite meeting to the 9th World Forestry Congress, held in Mexico City in the summer of 1985, the purpose of the consultation was to review and evaluate literature, unpublished reports, and other materials, and communications with foresters to ascertain the contributions of forestry in combating desertification processes. A major emphasis was placed on woodland formations, where most of the dryland forestry practices in the southwestern United States and northern Mexico occur.

Rarely is a review of this kind complete in assembling all of the relevant knowledge and information that is available. Nevertheless, this effort uncovered apparent gaps in knowledge that might be lessened through increased research and educational efforts. These gaps in knowledge, oriented more to wood production and utilization potentials than the subsequent listings, were grouped arbitrarily into three broad categories:

- Biological - including quantification of growth rates and subsequent yields, information for long-term, sustained yield management, and knowledge of tree and shrub regenerative practices.
- Socio-Economic - such as identification of supplies and demands for wood products, characterizations of marketing potentials, and recognition of social attitudes of local people.
- Managerial - specifying timing and techniques of harvesting, designations of land open to exploitation, and establishment of protected areas.

It also was suggested in this review that initial emphasis should be placed on alleviating biological and socio-economic gaps in knowledge. This emphasis, therefore, formed a basis for research programs to address ecological and managerial issues related to the management of woodland communities in the regions, especially in the encinal woodlands where relatively little research had been conducted. Management agencies, whose jurisdictions include lands on which woodland communities are found, were considered responsible for establishing and enforcing necessary administrative frameworks.

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[1] *Paper presented at symposium, Ecology and Management of Oak and Associated Woodlands: Perspectives in the Southwestern United States and Northern Mexico (Sierra Vista, AZ, April 27-30).*

[2] *Professor, School of Renewable Natural Resources, College of Agriculture, University of Arizona, Tucson, AZ 85721.*

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WORKSHOP ON MANAGEMENT OF OAK WOODLANDS IN SOUTHEASTERN ARIZONA

Participants in a workshop on the management of oak woodlands in southeastern Arizona, held in Sierra Vista, Arizona, in April, 12-13, 1988 (Ffolliott and Hasbrouck 1988), were asked to identify future research needs from which studies might be formulated. In conducting this exercise, the participants, who largely represented land management agencies and University of Arizona researchers, were divided into three groups to consider bio-physical, socio-economic, and administrative-managerial concerns. Each group was charged with identifying four to six study topics that could be addressed successfully within a 3-year period. There was no need for the participants to prioritize these studies, as they all were considered high priority concerns. The topics identified, which were more specific and multiple-use focused than those obtained in the FAO consultation, are listed below (Ffolliott and Lefevre, 1988):

Bio-Physical Concerns

- Role and influence of fire in the invasion of oak woodlands by juniper and manzanita
- Effects of different silvicultural treatments on overstory-understory relationships: influences on plant and animal communities
- Sexual and asexual regeneration of oak species: knowledge on the frequency and volume of acorn production
- Effects of grazing by herbivores on the general "health" of oak woodland ecosystems
- Water and soil conservation
- Entomological and pathological influences: importance of acorn borers and heart rot fungi
- Possibility of creating monocultures through silvicultural practices

Socio-Economic Concerns

- Effects of woodcutting and thinning operations on visual qualities
- Impacts of imported fuelwood from Mexico on market prices
- Price of fuelwood permits: relationship between price and theft of fuelwood
- Development of supply and demand curves for individual tree species
- Lack of adequate roads: considerations of closing unused roads
- Respective roles of commercial and non-commercial individual woodcutters

Administrative-Managerial Concerns

- Meeting wildlife management objectives and opportunities
- Trade-offs between fuelwood production and the production of livestock
- Geographic Information Systems (GIS): current needs and verification of existing database themes
- Utilization of commercial woodcutters in meeting management objectives
- Conversion of oak woodlands to juniper
- Further refinement of oak woodland management objectives
- Control of illegal woodcutting: law enforcement
- Improved recreational opportunities

The topics identified by the participants of the 1988 workshop have helped in the continuing research efforts important to the management of the encinal woodlands. Some of this research is reported in the current proceedings.

PARTICIPANTS OF 1992 SYMPOSIUM

In the final session of this symposium, participants were asked to identify research and management needs that would help further to fill gaps in our knowledge about the woodlands. These participants represented land managers, government and university researchers, wood products specialists, local ranchers, and environmentalists from the southwestern United States, northern Mexico, and other regions of the United States.

Some of the needs identified were similar to those suggested during the 1988 workshop, indicating continuing concerns. Several of the suggested topics bridged research and management concerns. No attempt was made to prioritize the issues identified. The encinal woodlands were emphasized, although research and management needs in other woodland communities also were mentioned. The topics have been grouped arbitrarily into broadly defined headings by the authors for presentation:

General Ecology

- Basic research on autecology of native plants and animals, including their habitat requirements and plant-to-plant and plant-to-animal relationships
- Better descriptions of plant communities and current health of natural communities
- Impacts of exclusion (fire, livestock grazing, and other perturbations) on woodland ecosystems
- Information on successional pathways within an ecosystem and between adjacent ecosystems, for

example, where oak woodlands come into contact with pinyon-juniper woodlands

- Information to create the proper diversities of woodland landscapes as part of current resource management goals
- Comparative ecological studies in similar woodland ecosystems in the southwestern United States and northern Mexico to determine common factors that influence the dynamics and biological diversities within the woodland communities

Tree Regeneration

- Basic ecophysiological research to define regenerative dynamics and explain relationships between management and regeneration
- Factors related to frequencies, cycles, and quantities of regeneration
- Natural regeneration in undisturbed stands in relation to maintenance of these stands
- Vegetative regeneration following disturbance in relation to recovery and subsequent stocking

Mast Crops

- Relationships between fuelwood harvesting levels and mast crops
- Phenology and physiology of mast production
- Influence of tree age and site characteristics on mast production
- Annual variations in mast production among oak species in a region

Wildlife

- Importance of mast to specific wildlife species
- Impacts of livestock grazing and residual vegetative covers on specific wildlife species, for example, quail, non-game birds, and deer
- Effects of fuelwood harvesting on wildlife species
- Type mappings of encinal woodland habitats to extrapolate research results and management options specific sites

Fire

- Descriptions of natural fire regimes within the encinal woodlands in relation to the health of the ecosystems
- Impacts of fire on threatened, endangered, and sensitive (TES) plant and animal species
- Potential uses of prescribed fire to meet land management objectives

Hydrology and Watershed Management

- Descriptions of hydrological processes in the encinal woodlands
- Relationships between the hydrologic and nutrient cycles
- Rates of erosion and sedimentation
- Impacts of land management activities and natural events on soil resources and long-term site productivities

Social Concerns

- Linkage of land management practices to the demographics related to increasing human populations within and adjacent to woodland communities
- Adjustments of land management practices to increased pressures placed on woodland communities for recreation and other non-traditional uses by the growing human population
- A continuing forum to get people together and coordinate research-management activities in the future

Inventory and Monitoring

- Inventories of wildlife species, both endemic and occasional users, that inhabit the encinal woodlands
- Inventories of the relationships between various plant and animal species and their respective habitat requirements in order to make decisions about proper management
- Development of monitoring techniques so that land management practices can be validated, modified, or abandoned
- Coordination of inventorying and monitoring activities among land management agencies within woodland ecosystems
- Integration of source data within GIS systems for subsequent analysis

Management

- Development and validation of ecological and hydrological simulation models to allow managers to predict the potential consequences of their decisions
- Establishment of long-term landscape goals for woodland communities that could be used to create proper diversities as part of land management activities
- Regulation of woodlands at the stand-level
- Review of California oak data, for example Plumb and Pillsbury (1987), to determine its appropriateness for extrapolation to Arizona, New Mexico, and northern Mexico
- Bibliographies of literature pertaining to the ecology and management of the woodlands (such as that presented elsewhere in these proceedings) be made available to managers

CONCLUSIONS

The woodlands of the southwestern United States and northern Mexico are utilized for fuelwood, livestock production, wildlife habitats, watershed protection, and recreation and tourism. Managers of these lands are attempting to integrate the various resources and people's needs with the health and sustainability of these woodland ecosystems. However, in many instances, aggressive, participatory woodland management is a relatively recent development.

Management of the woodland communities must be based on sound ecological information, but there are many gaps in our knowledge. Participants in the 1992 symposium, representing a broad range of interests and experiences, identified areas where additional research is necessary to properly manage these unique woodland ecosystems for their maximum health, function, and production.

LITERATURE CITED

Ffolliott, P.F. 1989. Arid zone forestry program: state of knowledge and experience in North America. Tech. Bull. 264. Tucson: University of Arizona, Arizona Agricultural Experiment Station. 80 p.

Ffolliott, P.F.; Hasbrouck, J.D., eds. Oak woodland management: proceedings of the workshop; 1988 April 12-13; Sierra Vista, AZ. Tucson: University of Arizona, School of Renewable Natural Resources. 88 p.

Ffolliott, P.F.; Lefevre, R. 1988. Future research needs. In: Ffolliott, P.F.; Hasbrouck, J.D., eds. Oak woodland management: proceedings of the workshop; 1988 April 12-13; Sierra Vista, AZ. Tucson: University of Arizona, School of Renewable Natural Resources: 73-74.

Plumb, T.R.; Pillsbury, N.H., tech. coords. 1987. Proceedings of the symposium on multiple-use management of California's hardwood resources; 1986 November 12-14; San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 462 p.

Salem, B.B. 1988. A strategy on the role of forestry in combating desertification. In: Whitehead, E.E.; Hutchinson, C.F.; Timmermann, B.N.; Vardy, B.G., eds. Arid lands: today and tomorrow. Boulder, CO: Westview Press: 841-869.

Free Trade Agreement: Implications for Agriculture and Natural Resources[1]

Harry Ayer[2]

The North American Free Trade Agreement (NAFTA) is currently being negotiated by the U.S., Mexico and Canada, and is expected to be signed in 1993. NAFTA is to greatly reduce barriers to trade — including tariffs, licensing requirements, marketing order regulations and phytosanitary regulations— among the three countries. Agriculture and forestry will be affected. The impact on particular commodity sectors will depend upon the labor intensity of production and harvest operations, the differences in wage rates between Mexico and the U.S., each country's productive capacity for particular commodities, and the current level of trade barriers. NAFTA is expected to increase production and export of vegetables and over time possibly citrus and beef from Mexico to the U.S.. NAFTA is likely to increase feed grain, citrus, apple, dairy products and small-timber forestry products production in the U.S. and export to Mexico, at least in the short run. NAFTA will not significantly impact cotton production in either Mexico or the U.S. NAFTA may, indirectly through its impact on consumer incomes in Mexico, increase the production of Mexican feeder cattle, but will not likely increase the export of Mexican feeders to the U.S. Finally, NAFTA will likely increase Mexico's demand for firewood produced in the Southwestern States. But whether or not NAFTA will increase cutting of the oak forests depends on U.S. government forest management policy on the public lands.

INTRODUCTION

Presidents Bush and Salinas de Gortari initiated talks for a bilateral free trade agreement between the U.S. and Mexico on June 10, 1990, and on February 5, 1991 Canada joined the negotiations now known as the North American Free Trade Agreement or NAFTA. No exact time schedule for the negotiations has been established, but many political observers believe that negotiations will be completed in late 1992 and then signed into law sometime in 1993.

NAFTA aims to eliminate or greatly reduce barriers to trade in one of the worlds largest market areas — the three countries have a combined population of 360 million people and a total gross national product of nearly $6 trillion. By comparison, the European Community's 12-nation effort to eliminate internal barriers to trade, called EC 92, encompasses a combined population of 320 million people. NAFTA is one of several current attempts to reduce trade barriers to gain lower prices, greater availability of goods and services, and higher incomes promised by freer trade among nations. Besides NAFTA and EC 92, other significant trade negotiations include the ongoing Uruguay Round of GATT, the South American Trade Agreement between Argentina, Brazil, Bolivia and Paraguay, and expected bilateral agreements between the U.S. and various Latin American countries.

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This paper focuses on the effect of NAFTA on agriculture, forestry and natural resources in the southwestern U.S. and Mexico. The story begins with the current level of trade between the U.S. and Mexico, which is already considerable.

U.S.-MEXICO AGRICULTURAL TRADE

The U.S. and Mexico are already important agricultural trading partners. In 1990 about 9% of all U.S. exports to Mexico were agricultural goods and about 9% of all U.S. imports from Mexico were agricultural goods. Mexico is the third largest export market for U.S. agricultural commodities. Corn, soybeans, dairy products, sorghum and meat lead U.S. agricultural exports to Mexico. Mexico is the second largest supplier of agricultural goods coming into the U.S.. Coffee, fresh and frozen vegetables, fresh and frozen fruit and live cattle lead imports.

Some 40 percent of Mexican agricultural imports enter the U.S. duty free. These goods are primarily "non-competitive" commodities — goods that the U.S. does not produce or that enter when production is limited. In the last five years Mexico has unilaterally and significantly reduced many restrictions on imports going into that country, including agricultural imports. Still, barriers to agricultural trade between the two countries remain. Of the 60 percent of agricultural imports coming into the U.S. subject to tariffs, the average fee is 7 percent ad valorem (of the value of the goods). Mexico's import tariffs on agricultural goods average 11 percent ad valorem and on forest products import duties are 10 - 20 percent. Besides these trade-restricting duties, both countries impose non-tariff trade barriers or NTBs. Mexico requires import licenses for several agricultural commodities which in effect imposes quotas on the amount which can be imported. The U.S. limits imports into this country through marketing orders for several fruit and vegetable products. The marketing orders, which have the sanction of government, can control the amount and quality of products sold through grade, size, quality or maturity standards. Both domestic and foreign sellers must meet the marketing order standards for products sold in this country. Finally, both countries limit imports of agricultural products through phytosanitary requirements—restrictions designed to protect animals and plants from disease and pests. Although some phytosanitary restrictions are necessary for the intended purpose, some observers believe that phytosanitary rules have been imposed without scientific evidence to support their imposition, and thus were erected primarily as trade barriers to protect domestic markets (United States International Trade Commission).

WHAT IS PROPOSED?

The most commonly mentioned changes in trade regulation call for a full elimination of import tariffs over time and the elimination of NTBs or reduction to the lowest possible level. Quotas and barriers associated with licensing, marketing orders and phytosanitary regulations are all to be eliminated or reduced. The 1989 U.S-Canada trade agreement eliminates agricultural import duties over a 10-year period, and such a schedule has been suggested for the new NAFTA. The proposed NAFTA expressly excludes changes in immigration regulations.

POTENTIAL IMPACTS ON AGRICULTURE AND FORESTRY IN THE SOUTHWESTERN U.S. AND MEXICO

Whether or not NAFTA will increase competition or open markets for particular sectors in the Southwest and Mexico depends on several factors: the labor intensity of crop and livestock production and processing, wage and benefit differentials between the two countries, current level of barriers to trade, and the differential in both countries' productive capacity to produce and process each commodity.

Wage and benefit differentials between the two countries are quite striking. Average wages plus benefits for manufacturing jobs in Mexico (maquiladoras), Singapore, South Korea, Taiwan and the U.S. are $1.63, $2,25, $2.94, $3.71 and $14.32 per hour respectively (Business Week). Agricultural wages are also substantially lower in Mexico than in the U.S.. For example, wage rates in the apple-growing region of Chihuahua in 1991 were about $.90 per hour (Cook, et al., p 397). Farm wage rates in Arizona and New Mexico were about $5.50 per hour in 1991 (Arizona Agricultural Statics Service, 1991, p 90). Although labor productivity may not be the same in the two countries, these numbers do indicate that wage differences can be substantial and for labor intensive commodities, give Mexico a production advantage. On the other hand, the cost of capital (interest rates) is significantly higher in Mexico than in the U.S. and for highly capital intensive sectors of modern agriculture, give U.S. producers an advantage. Also, differences in land productivity and water management can, in some cases, lead to significant yield advantages for U.S. producers. But these advantages may disappear. Mexico has recently taken major steps to improve the credit market and encourage both domestic and foreign investment in agriculture. Besides stimulating the credit market directly, Mexico is changing its long-standing land tenure policy to now encourage ownership and sale of land and make larger farm and ranch operating units legally feasible. As a result of these changes, investment in agriculture, technology and management may markedly improve (Cook and Shwedel).

Lettuce. Lettuce production and harvest are labor intensive. Approximately 70 percent of lettuce operating costs in Arizona are attributed to labor (Wade and Butler). The lettuce season in the Yuma area is similar to that in the Mexicali Valley and San Luis. From November through May the U.S. imposes a 6.48 percent ad valorem equivalent import tariff on lettuce (General Accounting Office). Each of these factors suggests that the removal of the U.S. import tariff may increase lettuce production in Mexico and exports to the U.S..

Cucumbers, Asparagus, Broccoli, Cauliflower, Onions, Squash and Tomatoes. Both U.S. exports of vegetables to Mexico, and imports of vegetables from Mexico have grown rapidly since 1988. By 1990 the U.S. exported about $150 million of vegetables to Mexico, but these exports were but a fraction of the total $1 billion plus of vegetables imported from Mexico. Fresh tomatoes are either the first or second most valuable Mexican agricultural export and in 1990 fresh tomato exports to the U.S. reached $428 million. Mexico does export processed tomatoes to the U.S., but the value of these exports is only about one-tenth the value of fresh tomato exports (Cook, et al., pp 28, 205, 239).

Production and harvest of cucumbers, asparagus, broccoli, cauliflower, onions and squash is labor intensive with wage costs of 40-80 percent of the variable operating costs (Wade and Butler, and Wade and Harper). One recent study of asparagus production and cut, pack and haul operations showed these costs to be about $17 per carton in the Mexicali-San Luis Valley compared to about $26 per carton in the Imperial Valley of California (Cook, et al., p 59). U.S. import tariffs on these vegetables range form 4.58 percent ad valorem equivalent for squash to 22 percent for cucumbers entering this country in May and June and September, October and November (General Accounting Office). Onions are also subject to marketing order restrictions (General Accounting Office). Many of these vegetables are produced in Mexico at the same time as in Arizona, and the infrastructure, including government surface irrigation facilities and strong grower associations, already exist. In the last few years Mexico has moved unilaterally to make foreign investment in Mexico more attractive, and new agricultural processing and vegetable freezing plants are already in place (United States International Trade Commission, p 4-6). Processing and freezing plants further strengthen the infrastructure for Mexican vegetable production. Too, Mexico has recently moved to change the ejido system by allowing ejido land to be rented or sold, and this added flexibility in ownership is expected to further encourage investment in production agriculture, including the horticultural sector of Mexico (Cook, et al., p 9). All of these factors suggest increased competition for Southwestern vegetable producers under a free trade agreement.

U.S. tariffs on fresh tomato imports vary from one part of the year to the next, but are considerably less than 10 percent ad valorem, in general. Marketing orders in both California and Florida also exist, and especially the Florida order operates to restrict the flow of fresh tomatoes, whether domestic or Mexican imports, into the marketing chain. As noted by Bredahl, Schmitz and Hillman, Florida growers have fought for years to keep Mexican tomatoes from entering the U.S. market. Although NAFTA would eliminate or greatly reduce the tariffs and presumably the marketing order restrictions, Mexican fresh tomato exports to the U.S. are not likely to increase significantly, at least for some time. Current barriers to fresh tomato imports are not generally very restrictive, Mexican yields have lagged far behind those of the U.S., the Mexican government has eliminated many imput subsidies, and the revaluation of the peso since 1987 all work to limit tomato production and export from Mexico. Too, Mexico's rapidly expanding population and income increases will cause more fresh tomato production to go to the domestic market (Cook, et al., 239-280).

The U.S. imposes a 13.6 percent ad valorem tariff on tomato paste and Mexican costs of production, and processing of tomatoes into paste is already competitive with California. Mexico stands to increase its share of the U.S. paste market once tariffs are eliminated (Cook, et al., pp 205-237).

Citrus. The U.S. imports some citrus, primarily as juice, from Mexico and exports a much smaller amount to Mexico. During the five-year period 1986 - 1990

U.S. imports of citrus from Mexico averaged $68 million per year (about $48 million of which was juice) compared to only slightly over $1 million in U.S. citrus exports to Mexico. (Spreen, Muraro, and Fairchild, pp 532 - 534).

Lemon, grapefruit and orange production in the Southwest are labor intensive — labor costs are nearly 80 percent of total operating costs for mature orchards (Hathorn and Wilson, see publication by crop). The U.S. import tariffs on lemons and oranges are 2.75 and 2.2 cents per kilogram respectively, or on an ad valorem equivalent in 1990, about 3.6 and 8.3 percent respectively. The U.S. import tariff on grapefruit is 1.8 to 2.9 percent per kilogram, depending on the month of entry, and in 1990 this tariff was an ad valorem equivalent of about 8.7 percent (Shields and Dong). The U.S. also has strong marketing orders for oranges and grapefruit, and phytosanitary requirements which Mexican exporters have not always met (United States International Trade Commission). In addition, increased foreign investment in processing facilities in Mexico add to the attractiveness of expanded citrus production there. These factors suggest that NAFTA may increase competition for Southwestern citrus producers, especially if NAFTA reduces marketing order restrictions. On the other hand, Mexico currently has a 20 percent tariff on most fruit imported into Mexico (Shields and Dong). And recent information for California indicates that returns per acre for oranges and lemons are higher there than in Mexico: per acre costs are a bit higher in California, but California yields are higher too (Batista). And importantly, the Mexican fruit fly is found in most of the citrus-producing areas of northeast Mexico, and fresh fruit shipments from infested areas will continue to be banned even under NAFTA (Spreen, Muraro, and Fairchild, p 497). Thus at least in the near term, and especially before improved varieties, management and technologies can be put in place in Mexico and the Mexican fruit fly controlled, Southwestern producers may benefit from lower Mexican import duties on citrus.

Apples. Only within the last five years has Mexico permitted apple imports from the U.S., and though the volume is still quite small, it is growing. In 1990 the U.S. exported about $7 million of apples to Mexico (Cook, et al., p 393).

California is one of the leading apple-producing states, but it is far behind the state of Washington which produces nearly half of all U.S. apples. Although apple production is fairly labor intensive (Wade, Wright and Kilby), most factors suggest that NAFTA may expand the market opportunities for U.S. apple producers. The demand for apples in Mexico is growing as population and incomes rise and as apples are substituted for papaya and other more perishable tropical fruit (Cook, et al, p 393). Mexico's climate is not generally as conducive to apple production as apple-growing areas of the U.S. In Chihuahua, Mexico's principal apple-producing state, frosts and hail are a major problem (Cook, et al, pp 385 - 412). Apple yields in Mexico are much lower than in the U.S. because of growing conditions and especially because of the lower level of production technology. Yields of even high-technology apple operations in Chihuahua are only 50 percent of average Washington yields (Cook, et al., p 396). Mexico imposes a tariff on apple imports of 15 to 20 percent ad valorem, has stringent import license controls, and some U.S. industry sources believe Mexico uses its phytosanitary rules to discriminate against orchard crops (United States International Trade Commission, pp 4-7, 4-8). Currently, only apples from certain counties of the state of Washington are permitted legal entry into Mexico (Cook, et al., p 396). Removal of these barriers to trade should improve market conditions for U.S. apple producers.

Cotton. The U.S. currently exports a very small amount of cotton to Mexico and Mexico exports a very small amount of cotton to the U.S.. Between 1985 and 1990 the U.S. exported, on average, less than 10 thousand metric tons of cotton annually to Mexico, an amount far less than one percent of total U.S. exports. Mexico exported less than 2 thousand metric tons of cotton annually to the U.S., on average, an amount less than 1 percent of total U.S. cotton consumption (U.S. Department of Agriculture). Under NAFTA, Mexico is unlikely to increase its cotton exports to the U.S., but the U..S. and the Southwest may modestly expand cotton production and supply of raw cotton to textile mills which export cloth to Mexico's apparel industry.

Mexico is unlikely to increase its exports to the U.S. for several reasons. Citrus and vegetable production in Mexico will likely become more profitable under NAFTA, and land and other resources drawn away from cotton. Cotton production is not particularly labor intensive — only 10 -12 percent of Arizona variable costs of production are for labor (Wade, Howell and Tickes; Wade and Husman) — and therefore Mexico's sharply lower wage rates are not a big advantage in cotton production. Too, many agricultural areas of Mexico have expensive or limited water for irrigation, just as in the Southwest, and water scarcity will limit expansion of water-thirsty cotton. And finally, U.S. barriers to cotton imports from Mexico are already minimal (Herndon and Schweikhardt). Although the U.S. has an annual import quota on both long and short staple cotton, raw cotton imports have not approached the quota limits in recent years (Stultz, Glade, Sanford and Meyer).

Southwestern and U.S. production of cotton may modestly increase under the NAFTA, but the final effect is not certain. Mexico currently imposes a 10 percent tariff on imported cotton and cotton is subject to Mexican phytosanitary regulations. The NAFTA would presumably eliminate or reduce these barriers to trade and expand the demand of Mexico's textile mills for U.S. cotton. On the other hand, US. textile mills are currently perceived to be more efficient and have lower costs of production than the those in Mexico, and it may be some time before Mexican textile mills can compete with those in the U.S. (Herndon and Schweikhardt).

Rather than increased cotton exports to Mexico, the NAFTA could result in a modest increase of cotton sales to U.S. textile firms who would in turn expand sales to Mexican apparel manufacturers. Lower wage rates give Mexico's apparel industry an advantage in the labor-intensive clothing assembly business, and the elimination of current quotas and tariffs imposed by the U.S. on imported apparel will likely expand apparel manufacture in Mexico. Current U.S. quotas on apparel coming into the U.S. from Mexico under the Multifiber Agreement (MFA) are equivalent to a 30 percent tariff, and removal of the quotas under a free trade agreement may expand Mexico's apparel industry (Herndon and Schweikhardt). Not all of the increase in U.S. yarns and threads and cloth going to Mexico for assembly into clothes would represent a net gain in our cotton sales, however. Part of the added manufacture of clothing in Mexico would be a replacement for clothing formerly manufactured in the U.S. or other countries.

Wheat. Some $51 million of wheat was exported from the U.S. to Mexico in 1990 (U.S. Department of Agriculture, April 1991), but these exports were far behind grain and feed exports of corn ($401 million) and sorghum ($328 million).

In the last three years Mexico has greatly reduced its barriers to wheat imports. Tariffs have been removed, and input subsidies reduced. And although wheat is one of the few commodities still under marketing control of CONASUPO (the Mexican government agency which controls the internal marketing and imports of some staple food commodities) trade is expected to be further liberalized in 1992 to allow private companies to import wheat (U. S. Department of Agriculture, April 1991; Peterson). Import licenses are still required and there are some phytosanitary regulations on wheat, but at least one source indicates these barriers have not been very restrictive (U.S. Department of Agriculture, April 1991). Thus, given Mexico's unilateral policies to free wheat trade, NAFTA may not have much additional impact on market opportunities for Arizona producers.

Beef. The U.S. currently exports mainly hides and meat and live fat cattle for slaughter to Mexico, and imports principally feeder cattle from Mexico. Under NAFTA, Mexico could increase its exports of beef to the U.S., but NAFTA is not expected to greatly affect the number of feeder cattle coming into this country.

The U.S. currently imposes about a 6 percent import tariff on meat coming from Mexico (Rosson, et al.). Under NAFTA, this import tariff would presumably be eliminated over time, and increase U.S. demand for Mexican meat. In addition, NAFTA is expected to continue the recent Mexican policies to encourage investment (both foreign and domestic), and investment in beef cattle feedlots and packing facilities could result. Five new slaughter facilities in Mexico have already met USDA requirements for exports of fresh, frozen or chilled boxed beef to the U.S. and two more are expected to meet approval in 1992 (Rosson, et al.). Finally, NAFTA will reduce current Mexican tariffs and licensing requirements on feed grains, and reduce the cost of Mexico's fat cattle production.

NAFTA will not greatly effect Mexican exports of feeder calves to the U.S. simply because few barriers to this trade still exist. Until recently, Mexico imposed an export tax of $60 per head for calves leaving the country, but in 1990 this was reduced to $30 per head, in 1991 to $15 per head, and in 1992 to $5 per head. Furthermore, the U.S. import tariff on live animals coming into this country is only about 1.5 percent ad valorem. By 1990 Mexico exported 1.14 million feeders to the U.S., but this was still only about 3 percent of all cattle slaughtered in the U.S. One estimate is that Mexican exports of feeders could reach 2.33 million head (Rosson, et al.). But changes in Mexico's feeder cattle exports are likely to occur with or without NAFTA.

Dairy. Dairy products and especially non-fat dry milk is one of the largest U.S. agricultural exports to Mexico. Mexico has a large population of nearly 90 million and it is rapidly expanding at about 2.3 percent annually. A large part of the population is young with over half below the age of 19 — an important factor in market considerations because milk products are more prevalent in the diets of young people. Mexican per capita dairy product consumption is less than half that of the U.S., in part because per capita incomes declined during much of the 1980s. But recent government policies and the proposed NAFTA offer encouragement that incomes will increase in the future, and milk consumption increase as well (McClain and Harris).

Milk production is not especially labor intensive, with labor costs typically about 8-10 percent of operating costs in the U.S.. Mexico imposes some import tariffs on fresh dairy products (10 percent), butter and butter oil (20 percent), evaporated milk (5 percent), condensed milk (5 percent), yogurts and buttermilk (20 percent), and cheeses (20 percent) and requires import permits on dry milk, evaporated milk, condensed milk and some cheeses (Mc Cain and Harris). These factors suggest that a free trade agreement, which eliminates or reduces tariffs and restricting permits, will increase U.S. exports of milk and milk products. On the other hand, feed costs are a relatively high portion of the costs of producing milk in Mexico and NAFTA will reduce the cost of feed for Mexican dairy producers. Too, changes in Mexico's land tenure policies to encourage larger farms and shift more farms to private ownership could stimulate needed forage production and capital availability for modern dairy farming.

Forest Products. Trade between the U.S. and Mexico in forest products has increased sharply in recent years. By 1990 solid wood exports from the U.S. to Mexico were over $270 million, a 236 percent increase from 1986. Softwood lumber has been our leading export (45 percent of total U.S. wood product exports), followed by hardwood lumber (9 percent), particleboard (7 percent) and softwood plywood (5 percent) (U.S. Department of Agriculture, April 1991). In 1990, the U.S. exported over $540,000 in firewood to Mexico (U.S. Department of Commerce, Trade Information Center). Mexico exported nearly $213 million of wood products to the U.S. in 1990, and the leading export was wood moldings ($86.8 million). Many of these exports, and other wood products exported from Mexico to the U.S., were manufactured from U.S.-grown timber because Mexico has more limited wood resources (U.S. Department of Agriculture, April 1991).

Nearly half of U.S. wood product imports from Mexico entered duty free, and the average rate on the half subject to duty was only 2.28 percent. The 1990 duty on softwood moldings, the single largest wood product import from Mexico, was 1.5 percent. The U.S. does not impose any nontariff barriers on wood product imports, except some phytosanitary restrictions.

Mexico, on the other hand, imposes significant import duties on wood products from the U.S.: logs (10 percent ad valorem), softwood lumber (10 - 15 percent), plywood (15 - 20 percent) and firewood (10 percent). Duties are waived, however, on wood imports which are further processed in Mexico and then reexported to the U.S.. In addition, Mexico has many nontariff barriers on wood product imports including import licenses, preferential quotas, financial clearing arrangements and phytosanitary requirements that have questionable scientific merit. Mexico does limit the importation of firewood through licensing and phytosanitary regulations (U.S. Department of Agriculture, April 1991; de la Calle).

Reductions in Mexican tariffs and nontariff barriers under NAFTA will increase Mexican demand for U.S. wood products. The effect of the increased demand on the Southwestern timber industry, however, is not straight forward. Most timber in the Southwest is on U.S. Forest Service lands. Cutting restrictions in the last few years substantially limit the amount of timber which can be harvested from Forest lands. The experience on the Apache-Sitgraves National Forest in Arizona is instructive (Lee). The Apache-Sitgraves is Arizona's top timber producer. The Land Management Plan of the late 1980s for the Apache-Sitgraves indicated 99 MBF could be harvested from the forest each year. Three years ago, this figure was lowered to 83 MBF. And since then, the Apache-Sitgraves has had difficulty attaining even that level. This year the Forest Service estimates only 50 MBF will be harvested (Lee). The reasons for the decreased supply relate to environmental concerns. Concerns about the Mexican Spotted Owl and the Gos Hawk have resulted in new Forest Service guidelines to reduce the cut of old, large trees, and cable- harvest over live streams has recently been prohibited. Timber harvest on Forest lands may well be controlled more by Congress than Forest Service managers, and Congress often responds to pressure from environmental interests (Stewart). Thus, while small growth timber is in relative abundant supply, and is available for poles, chips to produce particle board, small dimension lumber and pulp, the supply of large diameter trees, already limited in number, has been restricted even more. And within the last six months, lumber prices have climbed dramatically in response to the rise in housing starts. Mexico's increased demand could result in the harvest of more small-diameter trees for manufacture into products such as particleboard, but the effect on large diameter tree harvest is likely to be added upward pressure on the price of lumber rather than increased timber cut.

NAFTA will also likely increase Mexico's demand for firewood of the Southwestern U.S. As indicated, Mexico currently imposes a 10 percent tariff on firewood entering from the U.S., and under NAFTA the tariff would be reduced to zero over a period of time. Mexico also has import licensing requirements and phytosanitary restrictions on firewood imports which may be reduced through NAFTA. At a minimum NAFTA should make the licensing and phytosanitary restrictions more transparent--that is to make the scientific basis and appeals process more easily understood. Reduced barriers to trade will increase Mexico's demand for Southwestern U.S. firewood. On private lands, harvest of oak and other firewood will likely increase. But on public lands the increased demand for firewood may or may not result in added cutting. As in the case of large, old timber, U.S. agencies such as the Forest Service and Bureau of Land Management can limit cutting. NAFTA does not preclude management of our forests to meet our own domestic environmental goals.

ENVIRONMENTAL EFFECTS

Most environmental news of NAFTA focuses on its potential impacts on the border environment. Many border communities already have significant ground and surface water contamination and air pollution associated with population and economic growth. Many people are concerned that NAFTA will increase these problems. My comments here, however, will be limited to environmental effects that occur vis a vis agriculture and forestry.

Range. Much of Mexico's rangeland is currently overgrazed, and this is especially the case on ejido lands (Ogden). NAFTA will not result in increased export of Mexican feeder cattle, simply because the barriers to this trade are already minimal, as explained earlier. NAFTA could, however, have some secondary impact on feeder production in Mexico, and hence on pressure on the rangeland. If NAFTA helps raise incomes in Mexico, as hoped, the demand for beef will increase and spur calf production. Other policies, however, will likely have an even greater effect on the feeder cattle sector. Mexico is implementing a host of policies to increase economic efficiency and raise incomes which also will stimulate the demand for feeders. But other policies may encourage better care of the range. As mentioned above, financial markets are being strengthened to lower interest and make credit more readily available, and changes in the land tenure system may encourage investment in range management technologies like fencing and pasture rotation.

In the Southwestern U.S., NAFTA will not likely have much impact on the rangeland. As indicated, barriers to trade in feeders are already minimal, and NAFTA will not do much to increase our import of feeders and thereby affect pressure on Southwestern rangeland.

Forests. NAFTA will likely stimulate Mexican demand for lumber and forest products from the Southwest. However, as indicated above, U.S. Forest Service management policy increasingly limits the harvest of old, large-diameter trees because of environmental concerns to protect these trees and the ecosystems they support. Accordingly, greater demand for timber is more likely to raise timber prices than to significantly increase old-growth timber cut. It will be interesting, however, to see if environmental policies on the forest can be maintained under conditions of rising timber prices. Many of the environmentally oriented policies have been established at a time when the construction and timber industries were depressed. Recently, timber prices have risen substantially in response to new housing starts, and NAFTA could add to the upward pressure on timber prices, and likely heighten efforts of the timber industry to harvest more large trees from the National Forests. NAFTA will also increase Mexican demand for products produced from small diameter timber, and the smaller trees are in much greater supply and not currently subject to intense pressure for preservation. In fact, some forest scientists indicate that increased cutting of small-diameter trees enhances the forest (Stewart).

Finally, NAFTA will reduce trade barriers on firewood produced in the Southwestern U.S. and exported to Mexico. Mexican demand for U.S. firewood will increase but whether or not cutting increases depends on U.S. policy which controls cutting on public lands.

Pesticides. NAFTA is expected to increase vegetable and possibly citrus production in Mexico, and its export to the U.S.. Both U.S. producers and consumer groups have expressed concern that Mexican vegetable and fruit production is not subject to the strict regulation faced by U.S. producers, and that vegetable and fruit imports may have unacceptable levels of pesticide residues. A recent study funded by the American Farm Bureau indicates, however, that pesticide levels on Mexican vegetable and fruit imports are not significantly higher than imports from other countries, and are not significantly higher than residues found on domestic production (Newman). Mexico is following the tolerance standards for pesticide residues established by agencies of the United Nations when possible, and if those are not set, Mexico uses EPA standards.

REFERENCES

Arizona Agricultural Statistics Service, *1989 Arizona Agricultural Statistics*, Bulletin S-25, August 1990.

Arizona Agricultural Statistics Service, *1990 Arizona Agricultural Statistics*, Bulletin S-26, August 1991.

Armstrong, Dennis, Professor of Dairy Science, University of Arizona, personal communication, April, 1991.

Bredahl, Maury, Andrew Schmitz and Jimmye Hillman, "Rent Seeking in International Trade: The Great Tomato War," *American Journal of Agricultural Economics*, February 1987, pp 1-10.

Business Week, "Mexico: A New Economic Era," November 12, 1990, pages 102-113.

Cook, Roberta L, et al, "Implications of the North American Free Trade Agreement for the U.S. Horticultural Sector, in *NAFTA, North American Free Trade Agreement, Effects on Agriculture,* Volume IV, Fruit and Vegetable Issues, American Farm Bureau Research Foundation, 1991, pp.3 -476.

de la Calle, Luis, Ministry of Commerce, Mexican Embassy, Washington, D.C., personal conversation, May 21, 1992.

Food and Agricultural Organization of the United Nations, *Yearbook, Trade, Commerce, Comercio,* Vol., 42, 1988, page 271.

Foreign Agricultural Service, USDA, *Trade Policies and Market Opportunities for U.S. Farm Exports,* 1989 Annual Report, January 1990, page 172.

General Accounting Office, *U.S.-Mexico Trade: Trends and Impediments in Agricultural Trade,* GAO/NSIAD-90-85BR, Washington, D.C. January 1990, page 10.

Hathorn, Scott and Lowell True, *Arizona Citrus Budgets, Maricopa County,* Cooperative Extension, University of Arizona, January 1982.

Hathorn, Scott and Wilson, *Arizona Citrus Budgets, Yuma Mesa Ruby Grapefruit,* Cooperative Extension, University of Arizona, January 1982.

Hathorn, Scott and Wilson, *Arizona Citrus Budgets, Yuma Mesa Valencias,* Cooperative Extension Service, University of Arizona, January 1982.

Herndon, Cary and David Scheikhardt, "Implications of a North American Free Trade Area for the U.S. Cotton Industry," in *NAFTA, North American Free Trade Agreement, Effects on Agriculture,* Volume III, Grain, Oilseed and Cotton Issues, American Farm Bureau Research Foundation, 1991, pp.71 - 106.

Lee, Susan, Assistant Forest Timber Staff, Apache-Sitgraves National Forest, Springerville, Arizona. Personal communication, April 21, 1991.

Ogden, Phil, Professor of Range Management, University of Arizona, personal conversation, April 20, 1992.

Newman, Mark, "Pesticide Regulations and the NAFTA Negotiations," in *NAFTA, North American Free Trade Agreement, Effects on Agriculture,* Volume I, General Issues, American Farm Bureau Research Foundation, 1991, pp.35-69.

Peterson, W. Wesley, "The Implications of a Free Trade Agreement with Mexico for U.S. Grain and Oilseed Exports," in *NAFTA, North American Free Trade Agreement, Effects on Agriculture,* Volume III, Grain, Oilseeds and Cotton Issues, American Farm Bureau Research Foundation, 1991, pp.3 - 41.

Rosson, C. Parr et al, "The U.S.-Mexico Free Trade Agreement: Issues and Implications for the U.S. Livestock and Meat Sector," in *NAFTA, North American Free Trade Agreement, Effects on Agriculture,* Volume II, Livestock and Dairy Issues, American Farm Bureau Research Foundation, 1991, pp.1-94.

Spreen, Thomas H., Ronald Muraro and Gary Fairchild, "Analysis of the Impact of the North American Free Trade Agreement in the U.S. Citrus Industry," in *NAFTA, North American Free Trade Agreement, Effects on Agriculture,* Volume IV, Fruit and Vegetable Issues, American Farm Bureau Research Foundation, 1991, pp.477 - 507.

Stewart, Buddy, Regional Economist, Region 3, U.S. Forest Service, Albuquerque, New Mexico, personal conversation, April 21, 1992.

Stultz, Harold, Edward Glade, Jr., Scott Sanford, and Leslie Meyer, *Cotton: Background for 1990 Farm Legislation,* Economic Research Service, USDA, September, 1989, p. 14.

U.S. Department of Agriculture, *Agriculture in a North American Free Trade Agreement, An Interim Review,* Washington, D.C., April 1991.

U.S. Department of Agriculture, *Foreign Agricultural Trade of the United States: Fiscal Year Supplement,* Economic Research Service, Commodity Economics Division, 199 and various issues.

U.S. Department of Commerce, Trade Information Center, personal inquiry, May 26, 1992.

U.S. Forest Service, District Three Regional Office, Albuquerque, New Mexico. File data provided by Ms. Toni Capps on timber cut on Arizona's National Forests, April 17, 1992.

U.S. Forest Service, *Land Areas of the National Forest System,* FS-383, February 1992.

United States International Trade Commission, *The Likely Impact on the United States of a Free Trade Agreement with Mexico,* USITC Publication 2353, February 1991, pp. 4-6.

U.S. Department of Commerce, Bureau of the Census. Census data from computer print-outs provided in a personal conversation with Mr. Dan Buerk of the the Arizona Department of Commerce, April 1992.

Wade, James, and Marvin Butler, *1990 Arizona Vegetable Budgets, Yuma County,* Extension Bulletin 9014, College of Agriculture, Department of Agricultural Economics, University of Arizona, August, 1990, page 13.

Wade, James and Fred Harper, *1990 Arizona Vegetable Budgets, Maricopa County,* Extension Bulletin 9013, College of Agriculture, Department of Agricultural Economics, University of Arizona, August, 1990.

Wade, James and Steve Husman, *1991 Arizona Field Crop Budgets, Maricopa County,* Extension Bulletin 191006, College of Agriculture, Department of Agricultural Economics, University of Arizona, April 1991.

Wade, James, Sam Stedman and John Harper, *1990 Arizona Field Crop Budgets, Pinal County,* Extension Bulletin 9009, College of Agriculture, Department of Agricultural Economics, University of Arizona, April 1990.

Wade, James, N. Gene Wright and Michael Kilby, *Budgeting an Apple Orchard: Costs of Establishing and Operating an Apple Orchard in Southeastern Arizona,* Cooperative Extension Service, University of Arizona, December 1986.

Multiple Values of Woodlands in the Southwestern United States and Northern Mexico[1]

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Abstract.–Values of woodlands in the southwestern United States and northern Mexico for wood and livestock production, wildlife resources, watershed management, and recreation and tourism are described. Many of these woodlands continue to be used as they were in the past. Management is becoming more responsive to the multiple values of woodland communities and people's desires for these multiple benefits, however.

Woodlands of the southwestern United States and northern Mexico have been and continue to be harvested for fuelwood, fenceposts, and other wood products. Of equal importance, however, these woodlands also have values for livestock production, wildlife resources, and watershed management. As demands for these latter products and uses continue to increase, there is increasing awareness of the necessity to holistically plan and implement management practices that consider these multiple values in these woodlands on a long-term, sustainable basis.

The purpose of this paper is to describe multiple values of woodlands in the southwestern United States and northern Mexico. This paper is an introduction to this symposium, with more comprehensive presentations to follow.

REGION OF FOCUS

The region of focus for this symposium are woodland communities in Arizona and New Mexico, USA, and Baja California Norte, Mexico. It includes large portions of Sonora, Chihuahua, and Durango, Mexico, and California, Nevada, and Texas, USA. Portions of Baja California Sur and Coahuila, Mexico, and Utah and Colorado, USA, also support woodlands. Woodland communities considered comprised of oak, pinyon, juniper, and combinations thereof.

Natural ranges and descriptions of climate, physiography, plant and animal resources, and past and present land use practices of woodland communities of the southwestern United States and northern Mexico are presented elsewhere in these proceedings. However, a general description of the history of land use is warranted here.

HISTORY OF LAND USE

Many early Native American settlements were located in and adjacent to the woodlands. The climate was agreeable and comfortable, the growing season was long enough for production of agricultural crops, and there was an abundance of fuelwood for cooking and heating (Lockwood 1932, Randles 1949, Tucker and Fitzpatrick 1972, Young and Budy 1979). The same pattern of settlement continued during Spanish explorations, which depended upon woodlands for fuelwood, building materials, and food. Spaniards also used woodlands to obtain fencing for livestock and timbers for mining industries.

With the coming of the American pioneer from eastern regions of the United States, after 1840, there were additional demands for woodland products and uses. More fencing material was needed to control expanding herds of livestock, more fuelwood was required to supply increasing populations, and the use of timbers in mining industries continued. Demands for fuelwood continued until railroads reached the region, coal mining increased, and fossil fuels became available. However, since the early 1970s, demands for fuelwood increased once again in the woodlands, due largely to rising costs of fossil fuels.

Many of the woodlands continue to be used as they were in the past. However, management is becoming more responsive to multiple values of woodland communities and local people's desires for these multiple benefits. Selected trees are harvested for fuelwood, fenceposts, and other wood products. Grazing of livestock remains an important use. It is recognized that woodlands are habitats for many wildlife species, some of which are endangered. The woodlands are receiving increased recreational pressures compared to earlier years. Land management practices, therefore, are evolving to encompass all of these demands. The trend of multiple use is irreversible.

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STRUCTURAL CHARACTERISTICS

Relatively small, often multiple-stemmed, irregularly formed trees are found in woodlands of the southwestern United States and northern Mexico. Species compositions and densities depend largely upon site characteristics and climate. Intermingled with the trees are shrubs, grasses and grass-like plants, forbs, and succulents, often in parks and savanna-like mosaics. Openness of the landscapes is related to soil and site characteristics, and history of land use.

Tree densities in the woodlands vary considerably (Barger and Ffolliott 1972, Everett 1987, Ffolliott and Hasbrouck 1988, Lymbery and Pieper 1983, Paulsen 1975, Reynolds et al. 1970, Tausch et al. 1983, Tueller et al. 1979). Numbers of trees range from a few scattered individuals to several hundred stems per hectare. Volumes of stemwood vary from less than 2 to over 100 cubic meters per hectare. Growth is relatively slow (Barger and Ffolliott 1972, Ffolliott and Hasbrouck 1988, Meeuwig 1979, Meeuwig and Cooper 1981). Depending upon site, age, and density characteristics, growth ranges from 0.25 to 0.50 cubic meter per hectare, which converts into an annual growth rate of less than one percent.

Rates of growth are greatest in trees less than 30 centimeters in diameter at root collar (drc), although the volume of wood accumulation is greatest in larger stems. Growth is relatively fast throughout early and into middle stages of development. However, as trees become older, mortality increases to the point where net growth is negligible.

WOOD PRODUCTS

Processing of woodland tree species into wood products is important to the livelihood of people. Fuelwood and fenceposts are two wood products commonly obtained from this primary resource. Other wood products that can be made from smaller, irregular stems and capitalize on unique physical characteristics of the species offer utilization opportunities for furniture and novelty items.

Fuelwood

Trees in the woodlands have been utilized longer for fuelwood than for other wood products. Wood is still a principal fuel in many rural localities. Heat content, ignition, and burning characteristics are among the more important basic fuel characteristics (Reineke 1960). Judged by these criteria, woodland tree species make excellent fuelwood.

Volumes of fuelwood harvested are difficult to estimate. One problem that confounds these estimates is fuelwood commonly is measured and sold in stacked-unit equivalents, rather than solid wood contents. Nevertheless, it has been estimated that, in Arizona alone, 170,000 cubic meters of fuelwood was harvested annually in the late 1970s (Ffolliott et al. 1979). Most of this harvest was obtained from woodland communities in and around larger metropolitan areas.

Charcoal

Many of the woodland tree species are suited to charcoal production, although the markets are small and often local. In general, wood is about 50 percent carbon and, consequently, charcoal yields are proportional to the density of wood. Denser species are preferred, since charcoal yields per unit of volume are greater.

Amounts of wood that are processed into charcoal in the region are unknown. However, a weekly production rate of 7 to 10 metric tons has been suggested as minimum production levels for a full-time operation (Johnson 1965, Kotok 1955).

Fenceposts

Woodland tree species are utilized for fenceposts because of their outstanding durability. Large numbers of fenceposts were cut for local use and in commercial enterprises during the period of settlement in the southwestern United States and northern Mexico (Barger and Ffolliott 1972). However, in recent years, increased use of steel and preservative-treated wood posts has reduced markets for posts.

Annual cuts of woodland species for fenceposts in a five-state area of the southwestern United States (Arizona, Utah, Nevada, Colorado, and New Mexico) were estimated to be nearly 300,000 posts in the early 1970s (Barger and Ffolliott 1972, LeBaron 1968). It is presumed that the annual cut is less at the present time.

Junipers and oaks are popular fencepost species. Pinyon has not been favored, since it is a "non-durable" wood and rarely achieves a form that is suitable for posts.

Other Products

Woodland tree species have not been utilized widely for sawn products, although railroad ties and mine timbers are cut from pinyon for local use. Junipers and oaks occasionally are cut into lumber by smaller mills (Barger and Ffolliott 1972). This lumber is used most often in furniture and novelty items.

Pinyon is a source of edible nuts, a valuable product of the species. Size of nut crops vary with the particular year, although it averages 2 to 5 million kilograms annually (Hamilton 1965, Little 1941).

Pinyon Christmas trees, favored by local residents, also are sold outside the region, although demands have declined in recent years, due to a scarcity of marketable trees and trends to artificial Christmas trees.

LIVESTOCK PRODUCTION

One of the common uses of woodland communities is to provide forage for livestock that graze these ranges. Situated between lower deserts and higher montane forests, woodland ranges frequently hold the key to balancing livestock numbers and forage resources.

Types of Livestock

Principal types of livestock that are produced are cattle, sheep, goats, and horses. It is estimated that nearly 8.5 million cattle, 1.9 million sheep, and 1.7 million goats graze on these rangelands annually (Downing and Ffolliott 1983). Estimates of numbers of horses that graze the woodlands are unavailable.

Compositions of herds in the southwestern United States differ markedly from that in northern Mexico. A predominance of cattle is found in the former, while cattle as well as high proportions of sheep and goats graze in the latter. These differences are attributed to economical and socio-cultural orientations in the two countries.

Forage Resources

Important nutritional requirements are satisfied through consumption of forage species in the woodlands (Abdullahi 1981, Otsijina et al. 1982, Rumbaugh et al. 1982). However, at the same time, inverse relationships frequently exist between forage resources and densities of trees. As production of one natural resource increases, production of the other decreases, with magnitudes of the "tradeoff" depending upon inherent site qualities (Everett and Koniak 1981, Ffolliott and Clary 1982, Hennessy et al. 1983, Johnsen and Elson 1979, Perez-Garcia 1980, Yavitt and Smith 1983).

In the pinyon-juniper woodlands of the southwestern United States, efforts have been made to convert woodlands to forage plants by removal of tree overstories. It has been estimated that, in Arizona alone, over 725,000 hectares of pinyon-juniper woodlands has been converted for this purpose (Ffolliott et al. 1979). Most of these conversions occurred before the 1970s. Relatively little conversion currently takes place on public lands.

Methods by which trees and shrubs are killed in conversion activities are mechanical, chemical, and burning. Cabling has been a commonly implemented mechanical method of conversion, although chaining, bulldozing, and hand chopping and sawing also are used. Tree-killing chemicals have not been used extensively in recent years because of environmental concerns. Broadcast burning does not provide a high degree of selection, but it can be effective in conversion on some sites (Ahlstrand 1982, Bruner and Klebenow 1979, McGinty 1980, Wright et al. 1979, Young 1983).

Forage production frequently increased, severalfold on many areas, once tree and shrub overstories have been removed (Clary and Jameson 1981, Herbel et al. 1983, Hessary and Gifford 1979, McDaniel et al. 1982, Neff 1980, Rippel et al. 1983). To illustrate this point, pinyon-juniper rangelands, that produced annual forage levels of 250 to 300 kilograms per hectare before removal of trees, yielded increases of 100 to 200 kilograms per hectare following conversion (Clary et al. 1974). However, increases in forage production often cannot be sustained. The question of whether the sacrifice in wood resources warrants conversion to forage plants is answered only through an assessment of comparative values for these natural resources. It has been found that some combination of forage plants and wood generally will "optimize" joint production functions.

WILDLIFE RESOURCES

Wildlife resources in woodlands have value for both consumptive and non-consumptive purposes. In terms of consumptive use, management activities are centered on big game species and, to a lesser extent, on small mammals that are hunted. Wildlife management agencies in the southwestern United States and northern Mexico structure managerial strategies and action plans to obtain optimum levels of game production, consistent with other natural resource values.

One non-consumptive use of note is viewing of diverse and often unique bird populations in woodland communities. Opportunities for bird-watching bring large numbers of people into the region from outside areas, enhancing their recreational experiences.

Wildlife Populations

Wildlife populations are difficult to quantify, as measuring techniques are frequently based on "indirect" observations of the presence of animals, rather than on actual counts. Nevertheless, population densities for big game and small mammals have been estimated in woodland communities, with defecation rates as the basis. It is estimated that deer populations range from 1 to 1.5 adults per 100 hectares, and elk populations are less than 1 adult per 100 hectares (Ffolliott and Hasbrouck 1988). Rabbit populations average less than 3 adults per 100 hectares. Wildlife population densities are variable, with estimates of density largely dependent upon juxtapositions of habitats, weather patterns, and "productivity" of the populations.

Game animals furnish hunting opportunities for many people. Hunting success, a measure of licensed hunters that are successful during a regulated hunting season, for big game often ranges between 15 and 25 percent for big game species. Hunting success for small mammals is more difficult to quantify, as records are not complete. Hunting seasons for big game and small mammals frequently overlap, and, as a consequence, small mammals often are hunted as a "buffer" species when big game is scarce.

Wildlife management agencies have devoted more attention to non-consumptive uses of wildlife resources in recent years. Non-game species of birds, rodents, and reptiles play important roles in the functioning of woodland ecosystems in which they live. Furthermore, they frequently possess "aesthetic" values which are difficult to measure, unfortunately. Accordingly, species and habitat management practices aimed at non-game species have been and continue to be developed for implementation on a large, relatively intensive scale. Intensified efforts also are being made to retain wildlife species, both game and non-game, that are considered to be "threatened" in their natural habitats.

Habitat Conditions

Woodland communities are important habitats for many wildlife species. Land management activities that impact these habitats, therefore, are linked intrinsically to the well-being of wildlife resources (Brown 1984, Knipe 1960, Lymbery and Pieper 1983, Reynolds 1964, Reynolds et al. 1970, Springfield 1976, Swank 1958). When woodland trees are manipulated through these activities, habitat qualities are correspondingly modified (Collins and Urness 1981, Severson and Medina 1983).

Optimal populations of wildlife species depend largely upon maintenance of "favorable" environmental conditions and also a balance between these populations and their environment. Achieving this balance in woodland communities is a recognized goal of wildlife management agencies (Ffolliott 1981, Reyes Rodriguez 1983).

WATERSHED MANAGEMENT

Woodlands are not often thought of as watershed lands. However, water relationships in these areas can be more important than those in humid environments. Water is always in critical balance in these ecosystems, and this balance frequently is upset by actions of people. As a result, watershed management programs in woodland communities are implemented to meet a number of conservation and developmental goals.

Activities that are associated with watershed management programs in the woodlands can be grouped into one of three categories: activities which minimize adverse impacts to soil and water resources, management activities that are designed to increase yields of high quality water, and rehabilitative activities that are needed to bring a watershed from a "poor" condition into a productive state. Within these categories, watershed management problems and activities are described below.

Minimize Adverse Impacts to Soil and Water Resources

Due to the fragile nature of soil and water resources in woodland ecosystems, care must be exercised to protect these resources. Fortunately, extensive degradation of soil and water resources usually is associated only with "extreme" precipitation events in terms of excessive, intense rainfall. To ensure protection of these resources, preventative and control measures are incorporated into watershed management programs.

Many of the managerial activities that minimize adverse impacts to soil and water resources are similar to those employed to control erosion. Roads are not built in or near stream channels. Once roads are closed, they are seeded to grasses and forbs to control erosion. Harvesting of wood is restricted in periods of excessive rainfall. Grazing of livestock is monitored to ensure a minimal effect on the ecosystem.

Increase Yields of High Quality Water

Vegetative management on upstream watersheds is one approach to increase water yields. Experiments conducted throughout the world have demonstrated that water yields can be increased by changing structure and composition of vegetation on a watershed. The additional streamflow runoff is attributed to decreased evapotranspiration. To investigate potentials of water yield improvement by vegetative management in woodlands, experimental watershed studies have been conducted in representative communities. One way to illustrate the effects of watershed management programs on water yields is through an example.

Responses of water yields to conversion of pinyon-juniper woodlands to forage plants have suggested little change in annual streamflow runoff. Conversions of pinyon-juniper woodland overstories by mechanical methods has produced little or no significant increases in water yields when compared to conditions before conversion treatments (Baker 1984, Clary et al. 1974, Clary 1975, Ffolliott and Thorud 1975, Hibbert 1979). The only significant response of streamflow runoff to removals of pinyon-juniper woodlands was attributed to aerial application of a mixture of 2,4-D and picloram on one experimental watershed. Annual streamflow runoff increased 10 millimeter, or approximately 55 percent. However, because of environmental concerns over use of herbicides, results of this study have not been translated into operational programs.

A constraint in watershed management is to minimize detrimental effects to on-site soil resources. Sediment production from woodlands generally are relatively small, and, fortunately, there is little change in sediment yields after water yield improvement tests involving vegetative manipulations (Clary et al. 1974, Clary 1975, Ffolliott and Thorud 1975). Changes in concentrations of dissolved nutrients and heavy metals in streamflow runoff following these treatments also have been small.

Rehabilitative Activities

Management programs to rehabilitate watersheds also are implemented in the woodlands. Among these activities are control of gullies and mass wasting through construction of upstream check dams, establishment of a tree or shrub cover on degraded sites, and curtailment of wood harvesting, livestock grazing, and other exploitative practices.

Because woodland ecosystems, once degraded, are difficult to rehabilitate, emphasis is placed on incorporating activities which minimize adverse impacts to soil and water resources into planning of watershed management programs. By doing so, "chain-reactions" from initial loss of soil and water resources to an advanced state of degradation can be averted.

RECREATION AND TOURISM

Recreation and tourism collectively represent one of the largest income generators from woodland communities. On-site recreational opportunities in the woodlands including hiking, camping, sightseeing, and picnicking. Comprehensive statistics on the levels of these non-consumptive uses are incomplete (Conner et al. 1990). For whatever the reasons, however, a growing number of people from both within and outside of the region are spending considerable time in enjoying the unique woodland resources of the region.

NATIONAL PARKS, WILDERNESS AREAS, BIOSPHERE RESERVES

In the southwestern United States, the National Park Service administers 16 national parks, national monuments, and recreational areas, many of which contain components of woodland communities. Forest, woodland, and other resources on 14 of these sites have been protected for 50 years or more. Relatively high concentrations of archaeological sites also are found on these areas. Wilderness areas have been and continue to be designated in the region in response to the public's interests in protection of these areas. National parks and other reserves in northern Mexico also contribute to conservation of woodland ecosystems. Currently, there are five biosphere reserves, components of Unesco's Man and the Biosphere (MAB) Program, in the southwestern United States and northern Mexico which also help to protect unique woodland communities.

CONCLUSIONS

Harvesting of wood products likely will continue to be a primary interest within woodlands in the southwestern United States and northern Mexico. However, inherently low levels of growth, irregular stem forms, and a lack of markets for commercially processed wood products constrain intensive development. Fuelwood and fenceposts undoubtedly will remain the primary wood products. But, livestock production, wildlife values, watershed considerations, recreation and tourism, and ongoing environmental issues have heightened pressures on people to ensure that each of these other uses is given its due consideration.

LITERATURE CITED

Abdullahi, A. N. 1981. Forage preference of cattle and eland on a desert grassland in southern Arizona. PhD Dissertation, 197 p. University of Arizona, Tucson, Arizona.

Ahlstrand, G. M. 1982. Response of Chihuahuan desert mountain shrub vegetation to burning. Journal of Range Management 35:62-65.

Baker, M. B., Jr. 1984. Changes in streamflow in an herbicide-treated pinyon-juniper watershed in Arizona. Water Resources Research 20:1639-1642.

Barger, R. L., and P. F. Ffolliott. 1972. Physical characteristics and utilization of major woodland tree species in Arizona. USDA Forest Service Research Paper RM-83, 80 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Brown, D. E. 1984. Arizona's tree squirrels. 114 p. Arizona Game and Fish Department, Phoenix, Arizona.

Bruner, A. D., and D. A. Klebenow. 1979. Predicting success of prescribed fires in pinyon-juniper woodland in Arizona. USDA Forest Service Research Paper INT-219, 12 p. Intermountain Research Station, Ogden, Utah.

Clary, W. P. 1975. Multiple use effects of manipulating pinyon-juniper. p. 469-477. *In* Watershed Management Symposium. [Logan, Utah, August 11-13, 1975] American Society of Civil Engineers, Logan, Utah, 781 p.

Clary, W. P., and D. A. Jameson. 1981. Herbage production following tree and shrub removal in the pinyon-juniper type of Arizona. Journal of Range Management 34:109-113.

Clary, W. P., M. B. Baker, Jr., P. F. O'Connell, T. N. Johnsen, Jr., and R. E. Campbell. 1974. Effects of pinyon-juniper removal of natural resource products and uses in Arizona. USDA Forest Service Research Paper RM-128, 28 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Collins, W. Z., and P. J. Urness. 1981. Habitat preferences of mule deer as rated by pellet group distributions. Journal of Wildlife Management 45:969-972.

Conner, R. C., J. D. Born, A. W. Green, and R. A. O'Brien. 1990. Forest resources of Arizona. USDA Forest Service Resource Bulletin INT-69, 92 p. Intermountain Research Station, Ogden, Utah.

Downing, T. E., and P. F. Ffolliott. 1983. The social dimensions of rangeland management. p. 19-23. *In* Patton, D. R., J. M. de la Puente, P. F. Ffolliott, S. Gallina, and E. T. Bartlett. (tech. coord.) Wildlife and range research needs in northern Mexico and southwestern United States. USDA Forest Service General Technical Report WO-36, 108 p. USDA Forest Service, Washington, DC.

Everett, R. L. (compiler) 1987. Proceedings: Pinyon-juniper conference. USDA Forest Service General Technical Report INT-215, 581 p. Intermountain Research Station, Ogden, Utah.

Everett, R. L., and S. Koniak. 1981. Understory vegetation in fully stocked pinyon-juniper stands (*Pinus monophylla, Juniperus osteosperma*), Nevada. The Great Basin Naturalist 41:467-475.

Ffolliott, P. F. 1981. Integration of wildlife and other natural resources policies. p. 24-28. *In* Ffolliott, P. F., and G. Halffter. (tech. coord.) Social and environmental consequences of natural resources policies. USDA Forest Service General Technical Report RM-88, 57 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Ffolliott, P. F., and W. P. Clary. 1982. Understory-overstory relationships: An annotated bibliography. USDA Forest Service General Technical Report INT-136, 39 p. Intermountain Research Station, Ogden, Utah.

Ffolliott, P. F., and D. B. Thorud. 1975. Water yield improvement by vegetation manipulation: Focus on Arizona. National Technical Information Service, PB 246 055, 1,094 p. National Technical Information Service, Washington, DC.

Ffolliott, P. F., and J. D. Hasbrouck. (eds.) 1988. Oak woodland management: Proceedings of the workshop. School of Renewable Natural Resources, University of Arizona, 88 p. Tucson, Arizona.

Ffolliott, P. F., W. O. Rasmussen, T. K. Warfield, and D. S. Borland. 1979. Supply, demand, and economics of fuelwood markets in selected populations centers of Arizona. Arizona Land Marks 9:1-74.

Hamilton, A. 1965. A matter of a pinyon. American Forests 71:60-61, 74.

Hennessy, J. T., R. P. Gibbens, J. M. Tromble, and M. Cardenas. 1983. Vegetation changes from 1935 to 1980 in mesquite dunelands and former grasslands of southern New Mexico. Journal of Range Management 36:370-374.

Herbel, C. H., W. L. Gould, and W. F. Leifesta, and R. P. Gibbens. 1983. Herbicide treatment and vegetation response to treatment of mesquite in southern New Mexico. Journal of Range Management 36:149-151.

Hessary, I. K., and G. F. Gifford. 1979. Impact of various range improvement practices on watershed protective cover and annual production within the Colorado River Basin. Journal of Range Management 32:134-140.

Hibbert, A. R. 1979. Managing vegetation to increase flow in the Colorado River Basin. USDA Forest Service General Technical Report RM-66, 27 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Johnsen, T. N., Jr., and J. W. Elson. 1979. Sixty years of change on a central Arizona grassland-juniper woodland ecotone. Agricultural Review and Manuals ARM-W-7, 28 p. USDA Science and Education Administration, Washington, DC.

Johnson, W. H. 1965. Economic analysis of charcoal production from the pinyon-juniper type. Annual Project Report and Work Plan, Project 638, 12 p. Utah Agricultural Experiment Station, Ogden, Utah.

Knipe, T. 1960. The javelina in Arizona. Wildlife Bulletin 2, 96 p. Arizona Game and Fish Department, Phoenix, Arizona.

Kotok, E. S. 1955. The production of charcoal from Arizona mesquite. USDA Forest Service, Research Note 15, 6 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

LeBaron, A. D. 1968. Estimating profits from sales of pinyon-juniper products. Resources Series 43, 28 p. Utah Agricultural Experiment Station, Ogden, Utah.

Little, E. L., Jr. 1941. Managing woodlands for pinyon nuts. Chronicle of Botany 6:348-349.

Lockwood, F. C. 1932. Pioneer days in Arizona. 387 p. MacMillian Co., New York, N.Y.

Lymbery, G. A., and R. D. Pieper. 1983. Ecology of pinyon-juniper vegetation in the northern Sacramento Mountains. Bulletin 698, 48 p. New Mexico Agricultural Experiment Station, Las Cruces, New Mexico.

McDaniel, K. C., J. H. Brock, and R. H. Haas. 1982. Changes in vegetation and grazing following mesquite control. Journal of Range Management 35:551-557.

McGinty, W. A. 1980. Soil vegetation and livestock responses following spring burning of Edwards Plateau rangeland. PhD Dissertation, 213 p. Texas A & M University, College Station, Texas.

Meeuwig, R. O. 1979. Growth characteristics in pinyon-juniper (*Pinus monophylla/Juniperus osteosperma*) stands in the western Great Basin (USA). USDA Forest Service Research Paper INT-238, 22 p. Intermountain Research Station, Ogden, Utah.

Meeuwig, R. O., and S. V. Cooper. 1981. Site quality and growth of pinyon-juniper stands in Nevada. Forest Science 27:593-601.

Neff, D. J. 1980. Occurrence of game forage plants on experimental watersheds. 31 p. Arizona Game and Fish Department, Phoenix, Arizona.

Otsijina, R., C. M. McKell, and G. Van Epps. 1982. Use of range shrubs to meet nutrient requirements of sheep grazing on crested wheatgrass during fall and early winter. Journal of Range Management 35:751-753.

Paulsen, H. A. 1975. Range management in the central and southern Rocky Mountains: a summary of the status of our knowledge by range ecosystems. USDA Forest Service Research Paper RM-154, 34 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Perez-Garcia, A. 1980. Ecology of the oak communities on the eastern foothills of the Sierra Madre Occidental in Chihuahua. PhD Dissertation, 165 p. New Mexico State University, Las Cruces, New Mexico.

Randles, Q. 1949. Pinyon-juniper in the Southwest. USDA Yearbook 1949:342-347.

Reineke, L. H. 1960. Wood fuel combustion practice. USDA Forest Service Forest Products Laboratory, Report 1666-18, 9 p. Forest Products Laboratory, Madison, Wisconsin.

Reyes Rodriguez, J. J. A. 1983. Moderator's comments: current research strategies for range and wildlife management. p. 66. *In* Patton, D. R., J. M. de la Puente, P. F. Ffolliott, S. Gallina, and E. T. Bartlett. (tech. coord.) Wildlife and research needs in northern Mexico and southwestern United States. USDA Forest Service General Technical Report WO-36, 108 p. USDA Forest Service, Washington, DC.

Reynolds, H. G. 1964. Elk and deer use of a pinyon-juniper woodland in southern New Mexico. Transactions of the North American Wildlife and Natural Resources Conference 29:438-444.

Reynolds, H. G., W. P. Clary, and P. F. Ffolliott. 1970. Gambel oak for southwestern wildlife. Journal of Forestry 68:545-547.

Rippel, P., R. D. Pieper, and G. A. Lymbery. 1983. Vegetational evaluation of pinyon-juniper cabling in south-central New Mexico. Journal of Range Management 36:13-15.

Rumbaugh, M. D., D. A. Johnson, G. A. Van Epps. 1982. Forage yield and quality in a Great Basin shrub, grass, and legume pasture experiment. Journal of Range Management 35:604-609.

Severson, K. E., and A. L. Medina. 1983. Deer and elk habitat management in the Southwest. Journal of Range Management, Monograph 2, 64 p.

Springfield, H. W. 1976. Characteristics and management of southwestern pinyon-juniper ranges: The status of our knowledge. USDA Forest Service Research Paper RM-160, 32 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Swank, W. G. 1958. Mule deer in Arizona chaparral. Wildlife Bulletin 3, 109 p. Arizona Game and Fish Department, Phoenix, Arizona.

Tausch, R. J., N. E. West, and A. A. Nabi. 1983. Tree age and dominance patterns in Great Basin pinyon-juniper woodlands. Journal of Range Management 34:259-264.

Tucker, E. A., and G. Fitzpatrick. 1972. Man who matched the mountains: The Forest Service in the Southwest. 293 p. Superintendent of Documents, U.S. Government Printing Office, Washington, DC.

Tueller, P. T., C. D. Beeson, R. J. Tausch, N. E. West, and K. H. Rea. 1979. Pinyon-juniper woodlands of the Great Basin: Distribution, flora, vegetal cover. USDA Forest Service Research Paper INT-229, 22 p. Intermountain Research Station, Ogden, Utah.

Wright, H. A., L. F. Neuenschwander, and C. M. Britton. 1979. The role and use of fire in sagebrush-grass and pinyon-juniper plant communities: A state-of-the-art review. USDA Forest Service General Technical Report INT-58, 48 p. Intermountain Research Station, Ogden, Utah.

Yavitt, J. B., and E. L. Smith, Jr. 1983. Spatial patterns of mesquite and associated herbaceous species in an Arizona desert grassland. American Midland Naturalist 109:89-93.

Young, J. A., and J. D. Budy. 1979. Historical use of Nevada's pinyon-juniper (*Pinus monophylla / Juniperus osteosperma*) woodlands. Journal of Forest History 23:112-121.

Young, R. P. 1983. Fire as a vegetation management tool in rangelands of the Intermountain Region. USDA Forest Service General Technical Report INT-157, pp. 18-31. Intermountain Research Station, Ogden, Utah.

Ecology of Oak Woodlands in Arizona[1]

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Abstract.–Autecological and synecological research in oak (*Quercus* spp.) woodlands of Arizona has been limited to relatively few studies. Most autecological research has focused on emory oak (*Q. emoryi*) and Arizona white oak (*Q. arizonica*), the two most common species in these woodlands. Data on these species, and others where available, are organized and summarized according to life-history stage in the current paper. The synecology of oak woodlands is largely restricted to descriptions of species assemblages. Relying largely on indirect evidence, I speculate on the ecological role of various disturbances, and the response of woodlands to them. Possible avenues for future research are outlined.

INTRODUCTION

Oak (*Quercus*) woodlands and savannas occupy several million ha of arid and semi-arid wildlands in the southwestern United States and northern Mexico, and are representative of dryland forests and savannas throughout the world. Despite the areal extent and economic and ecological importance of woodlands and savannas, plant ecology research in them has been restricted to relatively few descriptive studies. Even rudimentary information concerning structural organization and development of vegetation has not been detailed, although Brown (1982) extensively described the type.

The history of scientific neglect is not restricted to oak woodlands; worldwide, dryland forests and savannas have only recently received attention from the academic community (Walker and Menaut 1988). This is particularly surprising for world savannas, since (1) they cover over a third of the world's land surface, (2) hominids probably evolved in savannas, and (3) historically, humans have tried to create savannas (by clearing forests or planting trees in grasslands) when settling in new areas.

Arizona's oak woodlands have been extensively used and disturbed since before the turn of the century. Oak trees were harvested from large areas to provide mine timbers and fuel for wood-fired smelters from about 1890-1910 (Bahre and Hutchinson 1985). Virtually all of southern Arizona was heavily grazed by livestock in the 1880s, and grazing continues today, though at much lower stocking rates. Historical fire frequencies have been altered by removal of fine fuel and fire suppression. Despite this long history of human occupancy and use, ecological relationships and response to various land-uses are largely unknown, and have only recently come under study.

This paper will summarize the current knowledge of oak woodland plant ecology. An overview of autecology of dominant species will precede a discussion of synecological relationships. The paper will conclude by considering important topics for future research.

AUTECOLOGY

Acorn Germination

Although the genus *Quercus* is subtropical in origin, most studies of *Quercus* germination have been restricted to cold-temperate regions. In these areas, red (or black, subgenus Erythrobalanus) oaks with immature embryos benefit from a period of stratification which permits embryo enlargement and subsequent germination (Korstian 1927; Aikman 1934; Schopmeyer 1974). Germination of white (subgenus Leucobalanus) oaks is usually not enhanced by stratification (Schopmeyer 1974; Vogt 1974).

Germination requirements have been intensively studied for only emory oak (*Quercus emoryi*) and Arizona white oak (*Quercus arizonica*), which are the most common of the 12 oaks in Arizona oak woodlands. Emory oak is a red oak, and Arizona white oak belongs to the white oak subgenus (Kearney and Peebles 1960). Interactions between length of storage (up to 90 days), type of storage (dry, room temperature vs. stratification), and germination medium (filter paper vs. soil) affected germination of both species (Nyandiga and McPherson 1992). Maximum germination in a controlled-environment chamber was 28% for emory oak and 48% for Arizona white oak. These acorns were collected in 1990: higher germination (72%) was observed with emory oak acorns collected in 1991 (McPherson unpubl. data).

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Percent germination is highest for recently-collected acorns, and declines rapidly with increased storage time, dropping to 0% within 60 days for both species (Nyandiga and McPherson 1992).

Decreased germination of Arizona white oak acorns following stratification is consistent with most published studies of white oaks (e.g., Griffin 1971, Farmer 1977, Borchert et al. 1989). Unlike emory oak, germination of most red oaks is enhanced by stratification. However, this response has been reported for oaks in cold-temperate regions which evolved with cold winter periods; germination requirements of subtropical oaks may differ from those of cold-temperate oaks.

Nyandiga and McPherson (1992) also conducted field trials with acorns of emory oak and Arizona white oak. Acorns were placed in the field coincident with acorn ripening (mid-summer for emory oak, mid-autumn for Arizona white oak). They found that (1) a covering of litter did not enhance germination of acorns at the soil surface, (2) germination was higher 7.5 and 15 cm below ground than at the soil surface, and (3) germination was complete within 30 days of acorn placement in the field. Germination of emory oak varied from 5 to 29%, and germination of Arizona white oak varied from 17 to 73% (Table 1).

It is clear from field observations that timing of acorn maturity and germination of semi-arid oaks are strongly correlated with the rainy season (Pase 1969, Griffin 1971, Schopmeyer 1974, Nyandiga and McPherson 1992), which usually begins in July in Arizona. Moisture content of acorns has been proposed as an indicator of viability and hence germination (Juhnel 1957, Griffin 1971, Schopmeyer 1974, Griffin 1976). Burial permits good seed-soil contact that enhances the possibility of acorns being moist throughout the imbibition period, leading several authors to attribute low germination of acorns on the soil surface to dessication (e.g., Shaw 1968, Griffin 1971, Snow 1972, Bennett 1977). Results of field trials (Nyandiga and McPherson 1992) were consistent with this observation: acorns on the soil surface were characterized by low viability and germination. However, data from laboratory trials demonstrated that moisture content alone did not explain variability in germination of emory oak and Arizona white oak. Stratified acorns had high moisture contents throughout the storage period, yet failed to germinate after 60 days. Regardless of storage conditions, germination was reduced when acorns were stored for only 30 days, compared to germination of unstored acorns (Nyandiga and McPherson 1992). Apparently factors other than moisture content are important in controlling germinability. Insect predation may contribute to viability loss in some species (Borchert et al. 1989), although this factor was of minor importance (< 2% acorn loss) for emory oak and Arizona white oak in 1990 (Nyandiga and McPherson 1992). Reduced amylolytic activity associated with storage may also contribute to decreased viability of acorns (Szczotca 1974, cited in Bewley and Black 1982).

Table 1. Mean (± SE) germination percentage of emory oak (*Quercus emoryi*) and Arizona white oak (*Q. arizonica*) acorns following burial in a semi-arid oak savanna in southeastern Arizona (from Nyandiga and McPherson 1992).

Depth (cm)	*Q. emoryi*	*Q. arizonica*
0 (bare)	5.0 ± 0.1a[1]	No data[2]
0 (litter)	10.0 ± 0.1a	16.7 ± 0.9a
7.5	28.8 ± 0.1b	72.5 ± 0.9b
15	21.3 ± 0.2b	73.3 ± 0.9b

[1] Means within a column followed by the same lower case letter are not different (P > 0.10) according to Fisher's LSD test.

[2] All acorns destroyed by seed predators.

The absence of seed dormancy in emory oak and Arizona white oak, combined with their tendency to mature coincident with a period of relatively high precipitation, suggests that they either use soil moisture to germinate immediately upon acorn drop or they do not germinate at all. Most germination of emory oak and Arizona white oak occurred within the first 30 days after placement in the field (Nyandiga and McPherson 1992). This observation is in agreement with Pase (1969) who noted that acorns of emory oak and shrub live oak (*Quercus turbinella*) germinated during the summer season immediately after they matured. Environmental conditions conducive to germination and establishment reportedly occur infrequently for most semi-arid oaks (Pase 1965, 1969, McCreary 1989, Borelli 1990). However, germination does not appear to be the life-history stage that limits replacement of overstory oaks: Nyandiga and McPherson (1992) reported field germination percentages of emory oak and Arizona white oak of no less than 5% in any microsite in 1990. Natural recruitment of emory oak was even higher the following year, at least to the 4-leaf stage (pers. observations), and Sanchini (1981) observed germination of large cohorts of emory oak and Arizona white oak in 2 of the 3 years she conducted censuses.

Seedling Establishment and Growth

A systematic survey of oak seedlings was conducted in several mountain ranges in southeastern Arizona (Borelli 1990). Few seedlings of any oak species were tallied, and establishment from the current year's acorns was particularly low (mean = 44.4 plants/ha). However, the study was conducted during 1989, when most oak species produced virtually no acorns, and precipitation during the establishment period was well below average – 1989 was the driest year since 1956 in southeastern Arizona (NOAA 1989). Given the rapid viability loss of acorns of these species (Nyandiga and McPherson 1992), 1989 probably was a poor year to survey oak seedlings. Sanchini (1981) censused first-year seedlings on permanent quadrats in 3 different years (corresponding to the 1978, 1979, and 1980 acorn crops), and reported mean emory oak seedling densities of

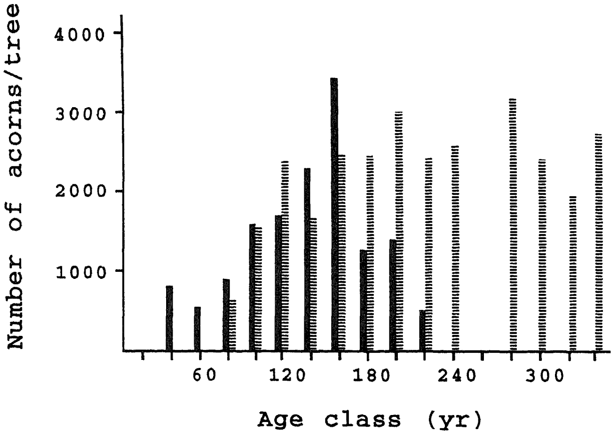

Figure 1. Age-class distribution of emory oak (solid bars) and Arizona white oak (broken bars) in southern Arizona, in 10-yr age classes (from Sanchini 1981).

300, 0, and 309/ha and mean Arizona white oak seedling densities of 636, 0, and 64/ha in 1978, 1979, and 1980, respectively.

Sanchini's (1981) study of emory oak and Arizona white oak population demography indicated that the former species was well-represented in young age classes: nearly 20% of 490 individuals sampled were less than 50 years old, and all age classes up to 200 years were represented (Fig. 1). Although no individuals of Arizona white oak were less than 30 years old, all other age classes up to 220 years were well-represented. Unlike strongly episodic establishment reported for most oak species, Sanchini concluded that recruitment in emory oak and Arizona white oak is a regular and constant process. A caveat is in order regarding this research, and other studies in which age data are reported: true age of Arizona's low-elevation oaks (e.g., emory oak, Arizona white oak) is impossible to determine with current technology. These oaks resprout from stumps and roots, so stem age may not represent plant age. Furthermore, stem age currently can not be reliably determined with dendrochronological techniques (T.W. Swetnam, pers. comm.). Future research may indicate that rings of these species are formed annually. Age data should be interpreted with considerable caution until more accurate measurements are available.

Pase (1969) evaluated survival of emory oak and shrub live oak seedlings over a 3-year period. About half the seedlings of each species died within the first year of germination, with nearly all the mortality attributed to drought. The survival curve of each species flattened at about 25% by the third year after germination. Mean height growth was 2.8 cm/yr for emory oak and 2.5 cm/yr for shrub live oak; root length for both species was about 17 cm/yr (Pase 1969).

Growth and Mortality

Aboveground growth rates have been studied for mature individuals of emory oak and Arizona white oak. Mean diameter growth rates (based on interpretation of growth rings) of emory oak and Arizona white oak were 0.35 and 0.24 cm/yr, respectively (Sanchini 1981). Again, these results should be judiciously interpreted because of the inability to accurately determine age of these oaks.

Most oaks resprout following top-removal by fire or harvesting (Cable 1957, Johnson et al. 1962, Pase 1969, Meyer 1988, Touchan 1991). Volume production of resprouting stems is rapid for the first few years (up to 704 cm^3/yr for emory oak, 472 cm^3/yr for Arizona white oak) (Meyer 1988). Stemwood volume production in stands is limited to 1.1-3.4 m^3/ha/yr (Touchan 1986). Biomass production of branches, leaves, and roots have not been estimated. Low productivity of these oaks is not surprising, considering the semi-arid climate and shallow, rocky, poorly-developed soils where they are found.

Analysis of life tables indicates that the risk of death remains essentially constant throughout the expected lifespan of emory oak and Arizona white oak trees (Sanchini 1981), implying that primary causes of mortality of both species are stochastic events (e.g., drought, ice storms, fire). Growth-ring data indicates that emory oak trees reach a maximum age of about 200 years, whereas Arizona white oak trees live to over 250 years (Sanchini 1981).

Flowering and Acorn Production

Little is known about reproductive cycles of semi-arid oaks. Data from growth-ring analysis indicates that emory oak produces acorns at a younger age (40 yr) than Arizona white oak (80 yr), and acorn production declines rapidly in the former species beyond 160 yr (Fig. 2) (Sanchini 1981).

Once mature, most Arizona oaks complete their reproductive cycles in a single year (Miller and Lamb 1985). Acorn production is highly variable among years and individual trees. For example, 61% (1978), 0% (1979), and 31% (1980) of emory oak and Arizona white oak trees in permanent quadrats produced acorns in consecutive years, and some of the trees

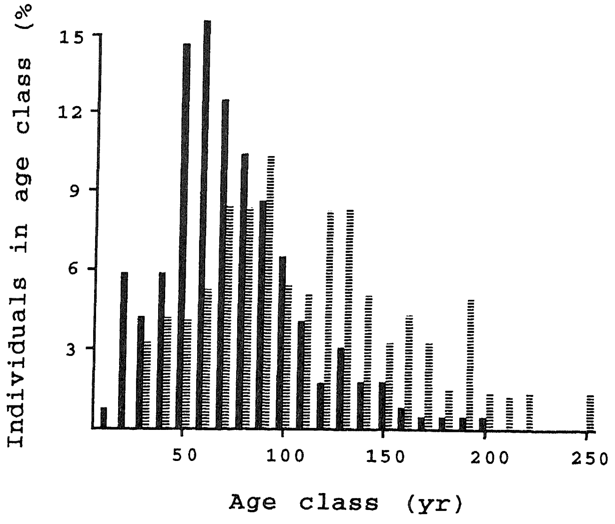

Figure 2. Mean acorn production, by age class, of emory oak (solid bars) and Arizona white oak (broken bars) in southern Arizona, in 20-yr age classes (from Sanchini 1981).

that produced acorns in 1980 did not produce acorns in 1978 (Sanchini 1981). Acorn production increased with increased crown area of trees, and a maximum annual production of 15,500 acorns for one emory oak tree and 32,600 acorns for a single Arizona white oak tree was noted (Sanchini 1981). Although Pase (1969) indicated that previous winter precipitation affects acorn production, acorn crop periodicity has not been studied in sufficient detail to determine environmental correlates (if any) associated with acorn production.

Post-dispersal seed predation by vertebrates (1-65% of acorns) and invertebrates (1-50% of acorns) can account for significant losses of acorns from the soil surface (Sanchini 1981, Nyandiga and McPherson 1992). Year-to-year variability is high: 68% of Arizona white oak acorns and 78% of emory oak acorns escaped predation in 1978, compared to fewer than 25% of acorns of each species in 1980 (Sanchini 1981). However, the presence of larvae in acorns does not preclude germination if the embryo is left intact (pers. observation). Although comprehensive seed fate studies have not been conducted, high levels of acorn production and survival during at least some years suggests that recruitment of neither species is limited by these factors.

Acorns of emory oak and Arizona white oak should be collected when the acorn cap can be separated from the seed without tearing the seed coat (Nyandiga 1991). Acorns that appear sound should be further screened by flotation: acorns that float should be discarded. Dark green acorns are mature enough to germinate; however, germination of brown emory oak acorns (86%) exceeded that of dark green acorns (68%) in controlled-environment studies (McPherson unpubl. data). Acorns should be placed in moist sand or filter paper as soon as possible after collection and screening; viability declines rapidly, regardless of storage conditions (Nyandiga and McPherson 1992).

Semi-arid temperate oaks are characterized by slow growth rates, particularly as seedlings. However, low mortality rates and long life spans, in association with relatively high levels of acorn production, germination, and establishment, suggest that these woodlands produce sufficient numbers of individuals to maintain or increase current densities. Recruitment of seedlings into the overstory may occur infrequently on some sites, as has been reported in California woodlands (McClaran and Bartolome 1989b, Standiford et al. 1991). Limited evidence from southern Arizona indicates a normal distribution of size and age classes (Sanchini 1981). Obviously, changes in the physical environment or disturbance regimes could alter patterns of recruitment and mortality.

SYNECOLOGY

Community Description

Community-level processes have been particularly poorly studied in oak woodlands, although the type has been extensively described. For example, Axelrod (1958) outlined post-Cretaceous development of the Sierra Madrean flora, Goldberg (1982) described soil-vegetation relations in Mexican woodlands, and Brown (1982) broadly outlined plant associations. Plant community distributions have been described along elevational gradients in southeastern Arizona at a coarse grain of resolution (Wallmo 1955, Marshall 1957, Whittaker and Niering 1964, 1965, Niering and Lowe 1984). For example, Niering and Lowe (1984), working in the Santa Catalina Mountains, described the band of vegetation between 1220 and 1520 m elevation as "open oak woodland" and the band between 1520 and 2130 m as "pine-oak woodland." Vegetation has not been studied within any of the broad communities outlined by these authors. Oak woodland grades into oak savanna, then semi-desert grassland, at the drier (and lower) end of type. Emory oak or Mexican blue oak (*Quercus oblongifolia*) typically are the dominant oaks in these savannas. At high elevations, oak woodland grades into oak-pine woodlands, then pine or mixed-conifer forests.

In recognition of the existing information void, stand structure data were obtained from the USDA Forest Service and analyzed (McPherson unpubl. data). The Forest Service, via its Forest Survey program, conducts inventories of forests and woodlands in the United States on a 10-year cycle. Arizona's most recent inventory was completed in 1985, and edited data were released in 1989. The primary goal of Forest Survey is to assess renewable resources for forest lands of the U.S. (e.g., Collins 1989). Field procedures for the Arizona inventory are detailed in a lengthy publication (USDA Forest Service 1985). The following variables were considered for this analysis: elevation, aspect, slope, evidence of disturbance, and diameter at root collar (DRC) of all woody plants greater than 7.5 cm DRC. Frequency (%), density (stems/ha) and basal area (m^2/ha) of sampled taxa were calculated from these data. Arizona white oak, emory oak, Mexican blue oak, gambel oak (*Quercus gambelii*), and silverleaf oak (*Q. hypoleucoides*) were identified to the species level, but other evergreen oaks were grouped into a single category. No attempt was made by Forest Survey to identify acacia (*Acacia* spp.), madrone (*Arbutus* spp.), or mesquite (*Prosopis* spp.) beyond the genus level.

Stands were sampled between 1160 and 2320 m elevation on slopes from 0 to 80%, on all aspects. Three-fourths of the stands occurred on National Forest land, and two-thirds were between 1400 and 1800 m elevation. Stand-level disturbance was observed in 13% of the stands, with fire (5%) being the most common disturbance. Disease (3%), fuelwood harvesting (3%), mechanical woody plant control (1%), and land-clearing (1%) were listed as additional disturbances.

Species composition was strongly influenced by elevation (Table 2), with high species turnover from the lowest to highest elevation zone. Only one

Table 2. Frequency (F; %), mean density (D; stems/ha), and mean basal area (BA; m^2/ha) of tree species on an elevational gradient in oak woodland stands of Arizona.

	Elevation (m)														
	< 1400			1400-1600			1600-1800			1800-2000			> 2000		
Species	F	D	BA	F	D	BA	F	D	BA	F	D	BA	F	D	BA
Acacia sp.	7	5	19	0	0	0	0	0	0	0	0	0	0	0	0
Juniperus erythrocarpa	7	12	50	3	10	48	0	0	0	0	0	0	0	0	0
Prosopis sp.	7	7	26	10	8	37	3	7	37	0	0	0	0	0	0
Juniperus deppeana	14	9	36	23	8	40	29	11	56	55	9	50	0	0	0
Quercus oblongifolia	21	23	96	10	3	16	9	7	33	9	20	114	0	0	0
Quercus emoryi	29	7	31	57	12	58	47	13	69	27	21	121	0	0	0
Other evergreen Quercus spp.	71	20	82	53	14	64	74	26	137	73	17	96	75	37	236
Pinus edulis	0	0	0	3	7	35	12	12	64	0	0	0	0	0	0
Quercus gambelii	0	0	0	3	5	24	3	17	93	0	0	0	0	0	0
Quercus hypoleucoides	0	0	0	3	5	22	12	16	83	45	37	212	25	7	47
Quercus arizonica	0	0	0	10	12	56	26	9	49	45	23	135	25	7	47
Juniperus scopulorum	0	0	0	0	0	0	3	2	13	0	0	0	0	0	0
Juniperus monosperma	0	0	0	0	0	0	3	10	50	0	0	0	0	0	0
Pinus ponderosa	0	0	0	0	0	0	3	2	13	0	0	0	0	0	0
Pinus discolor	0	0	0	0	0	0	27	10	55	55	11	61	25	2	16
Pinus leiophylla	0	0	0	0	0	0	0	0	0	9	10	56	0	0	0
Cercocarpus breviflorus	0	0	0	0	0	0	0	0	0	18	12	73	0	0	0
Pinus engelmannii	0	0	0	0	0	0	0	0	0	9	7	41	25	7	46
Cercocarpus betuloides	0	0	0	0	0	0	0	0	0	0	0	0	25	25	158
Arbutus sp.	0	0	0	0	0	0	0	0	0	0	0	0	25	12	77

(grouped evergreen *Quercus* spp.) of the 13 taxa represented in these two zones was shared. This was the only taxa found in all elevational zones, although emory oak, Mexican blue oak, silverleaf oak, and Arizona white oak were broadly distributed across the elevational gradient. Relative to other oaks, gambel oak occupied a narrow band at middle elevations. Gambel oak is commonly found in pine forests at higher elevations than reported here. Acacia was restricted to a single, low-elevation plot, reflecting its membership in the semi-desert grassland. Pines (*Pinus* spp.) were common above 1600 m, although some individual pine species were restricted to a single elevational zone [e.g., ponderosa pine (*P. ponderosa*) and Chihuahua pine (*P. leiophylla*)]. Minor upper-elevation species included hairy mountain-mahogany (*Cercoparpus breviflorus*) (1800-2000 m), Apache pine (*Pinus engelmannii*) (>1800 m), and birchleaf mountain-mahogany (*Cercocarpus betuloides*) and madrone (> 2000 m). Personal observations indicate that ponderosa pine also occurs at higher elevations than reported in the Forest Survey data.

Overstory-Understory Relations

Typical understory species in Arizona oak woodlands include perennial bunchgrasses and several species of herbaceous dicots. Most graminoids are warm-season (C_4 photosynthetic pathway) plants, commonly including muhly (*Muhlenbergia* spp.), grama (*Bouteloua* spp.), three-awns (*Aristida* spp.), plains lovegrass (*Eragrostis intermedia*), Texas bluestem (*Andropogon cirratus*), Arizona cottontop (*Trichachne californica*), and green sprangletop (*Leptochloa dubia*). Cool-season (C_3) plants, including pinyon ricegrass (*Piptochaetium fimbriatum*), junegrass (*Koelaria cristata*), bottlebrush squirreltail (*Sitanion hystrix*), and sedges (*Cyperus* spp.) are found throughout mid- to high-elevation sites and under trees at lower elevations. Several species of perennial and annual forbs emerge in early spring

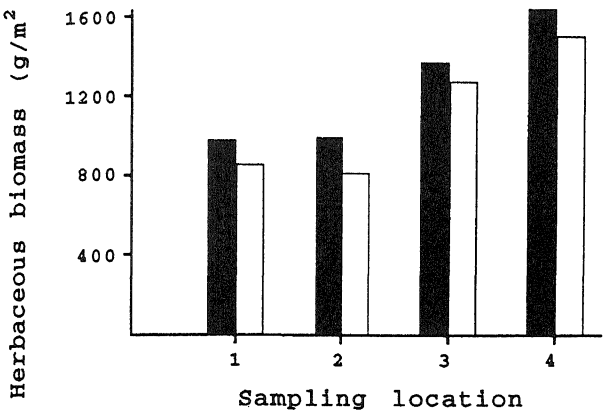

Figure 3. Mean aboveground herbaceous biomass in 1990 (solid bars) and 1991 (open bars) in an emory oak savanna, southern Arizona. Standard error bars are too small to be visible on the figure. Sampling locations were (1) midway between tree bole and canopy edge, (2) at canopy edge, (3) 2 m from canopy edge, and (4) in interstices between trees (from Haworth 1992).

following snowmelt. A second group of forbs emerges coincident with the summer monsoon.

No systematic evaluation of overstory-understory relations has been undertaken in oak woodlands of Arizona. Research in an emory oak savanna (Haworth 1992) indicates that herb biomass is reduced under the canopies of isolated emory oak trees (Fig. 3). In contrast to similar studies in temperate savannas (e.g., Everett et al. 1983, McClaran and Bartolome 1989a, Callaway et al. 1991, McPherson et al. 1991), species composition of herbs was not affected by trees, even large ones (up to 70 m^2 in canopy area). These data were collected at the oak woodland/semi-desert grassland boundary. More research is warranted to assess changes in herbaceous species composition and interactions over the broad elevational range of oak woodlands.

Disturbance History and Response

The relative absence of observed disturbances (e.g., by Forest Survey in 1985) does not imply that disturbance is unimportant in regulating structure of oak woodlands. Undetected disturbances may have exerted considerable control over stand structure and productivity. For example, modern fires in closed-canopy oak woodlands probably are high-intensity, stand-replacing fires (Marshall 1963, Swetnam et al. 1989) that leave little observable evidence (e.g., fire scars). Additionally, grazing by large herbivores may significantly alter stand structure while leaving little direct evidence (White 1966, Griffin 1971, Sanchini 1981).

Historically, fires probably occurred about every 10-20 years at the lower end of the oak woodland, adjacent to semi-desert grasslands. Fires occurred every 10-20 years in the semi-desert grassland (Wright and Bailey 1982). Fine fuel was nearly always adequate to support fire spread [> 1000 kg/ha of fine fuel is usually required to sustaining grassland fires (Wright and Bailey 1982, Clark 1983), and aboveground biomass in emory oak savannas exceeds this threshold (Haworth 1992)]. An extended period of hot, dry weather occurred every year in these woodlands, and ignition sources (lightning, native Americans, early Anglos) were available. Since barriers to fire spread between semi-desert grasslands and oak woodlands were historically absent, it can be inferred that grassland fires frequently burned into oak woodlands. These fires burned quickly and with low intensity in open oak woodlands with continuous grassy understories. Oaks are generally capable of surviving this type of fire (Wright and Bailey 1982), and the herbaceous layer responds quickly. Fires probably thinned these open stands by killing young woody plants that established after the last fire. Extensive cattle grazing and construction of fire breaks (e.g., roads, pastures, housing developments), in association with efficient fire suppression, may have contributed to greatly reduced fire frequencies after the mid-1800s.

Statements about fire history and effects in closed-canopy oak woodlands are much more speculative than those in low-elevation open stands. Fires rarely leave visible evidence (e.g., fire scars) in these woodlands except at high elevations where Apache pine and ponderosa pine are common. The absence of an annual signal in growth rings of these species further exacerbates the problem (although silverleaf oak shows some promise in this regard; T.W. Swetnam, pers. comm.). Therefore, use of dendrochronological techniques to determine fire history is largely restricted to stands dominated by pines, not oaks (e.g., Swetnam et al. 1989). Forest Survey workers reported seeing evidence of fire in only 5% of the stands they visited. Two hypotheses may explain the relative absence of physical evidence of fire: (1) fires are rare, and (2) intense, stand-replacing fires occur periodically but leave little evidence.

Historical mean fire intervals in adjacent communities were quite high: at least every 10-20 years in semi-desert grasslands below oak woodlands (Wright and Bailey 1982) and about every 7 years in pine communities above oak woodlands (Baisan and Swetnam 1990). Given an annual period of hot, dry weather, an abundance of ignition sources, and frequent fires in adjacent communities, it seems unlikely that oak woodlands escaped fires altogether. Newspaper articles from 1859 to 1890 included frequent accounts of large fires in woodlands throughout southeastern Arizona (Bahre 1985). Records from the Coronado National Forest (cited in Barton 1991) indicate that fires continue to occur throughout the Chiricahua Mountains, but the incidence of fires is low (less than 2 fires/ha/100 yr) between 1200 and 2000 m elevation, where oak woodlands and savannas are best developed.

Aboveground portions of most species found in oak woodlands are susceptible to damage by fires (Barton 1991, Bennett and Kunzmann 1992). Apache pine appears exceptional in this regard (Barton 1991). However, most tree species appear to respond favorably to fires. All of the oaks resprout profusely, and Chihuahua pine establishes quickly from seed in recently-burned areas (Barton 1991). Thus, the hat fires were absent or infrequent. Fires may have een relatively common in the past, with reductions 1 fire frequency and associated vegetation change in he last century contributing to loss of physical vidence. For example, cambial development may onceal fire scars in semi-arid oaks (McClaran and artolome 1989b). Nonetheless, historical fire freuency and behavior are difficult to estimate with vailable information.

The absence of reliable data on oak woodland fire istory and effects led Bennett and Kunzmann (1992) conclude that prescribed fires should not be conucted in these communities when objectives include aintaining natural ecological processes. This imies that the absence of fire represents a "control" or atural" situation, which is clearly incorrect. The osence of data, albeit serious, does not excuse action; this is especially true in these woodlands, here it seems inconceivable that fires were absent storically.

In addition to altering fire frequency, cattle grazg (which is ubiquitous in oak woodlands) may affect mmunity structure by direct and indirect effects of erbivory. Grazing should favor oak establishment if mpeting grasses are preferentially grazed. Ineased abundance of woody plants in many of the orld's grasslands concomitant with cattle grazing pport the latter hypothesis (e.g., Bogusch 1951, ackburn and Tueller 1970, Kelly and Walker 1976, ngh and Joshi 1979, van Vegten 1983, Harrington al. 1984, Bucher 1987, Archer et al. 1988, cPherson and Wright 1988). However, cattle portedly adversely affect oak seedling recruitment Arizona (Bahre 1977) and California (McClaran d Bartolome 1990).

Studies of population demography are rare for izona oaks, but Sanchini's (1981) growth-ring alysis showed that stem age of emory oak and izona white oak followed a normal distribution. If ese stems represent established germinants (vs. sprouting by established individuals) and we sume stem age estimates are accurate within a few ars, then establishment of these oaks does not pear to be episodic. Furthermore, many individuals both species have established in the last 50 years. fact, Sanchini (1981) concluded that emory oak ablishment is enhanced by the relatively constant sturbance regime in these woodlands.

Fuelwood cutting played an important historical e in these woodlands around the turn of the ntury. Woodlands near mines often were stripped all trees (Bahre and Hutchinson 1985). Oaks were pecially valuable as a source of fuelwood, but trees re also used for fenceposts, mine timbers, corrals, d construction. Evidence of intensive harvesting ring the mining period is still present--43% of lividual oak trees within 40 km of Tombstone (a jor mining town) showed signs of cutting as late as mid-1980s (Bahre and Hutchinson 1985).

There is little question that oak woodlands have been, and continue to be, subjected to considerable natural and anthropogenic disturbance. The net effect of these activities is difficult to evaluate. For example, reports of historical changes in the oak woodland/semi-desert grassland boundary are mixed. Paleoecological data suggest that oak woodlands have shifted upslope in concert with warmer and drier conditions since the Pleistocene. This interpretation is consistent with upslope movement of most woody species in the last 40,000 years (Betancourt et al. 1990). Hastings and Turner (1965) concluded that oak woodlands have been replaced by semi-desert grasslands at an increasing rate since 1880, blaming oak mortality at the woodland/grassland boundary on an increasingly xeric climate. Bahre (1991) challenged this interpretation, concluding that the woodland/grassland boundary has been stable since the 1860s. Direct evidence from stable-carbon analysis of soil organic matter indicates that emory oak trees are recent occupants of former grasslands (Fig. 4), implying that the boundary is moving downslope. Thus, the relatively easy question "which direction has the woodland/grassland boundary moved?" remains unanswered. Density of trees probably has increased in the last century, at least in the lower portion of the oak woodlands (Bahre 1991). Increased oak density may be attributed to decreased frequency and severity of fire and fuelwood harvesting in the last century.

Prediction of future changes in distribution and composition of oak woodlands will prove very difficult, given the background of recurrent disturbances and anticipated changes in climate (Emanuel et al. 1985, Grotch 1988). Distributional changes at low elevations will include expansion into grasslands if conditions remain conducive to establishment of oak seedlings in semi-desert grasslands. In fact, increas-

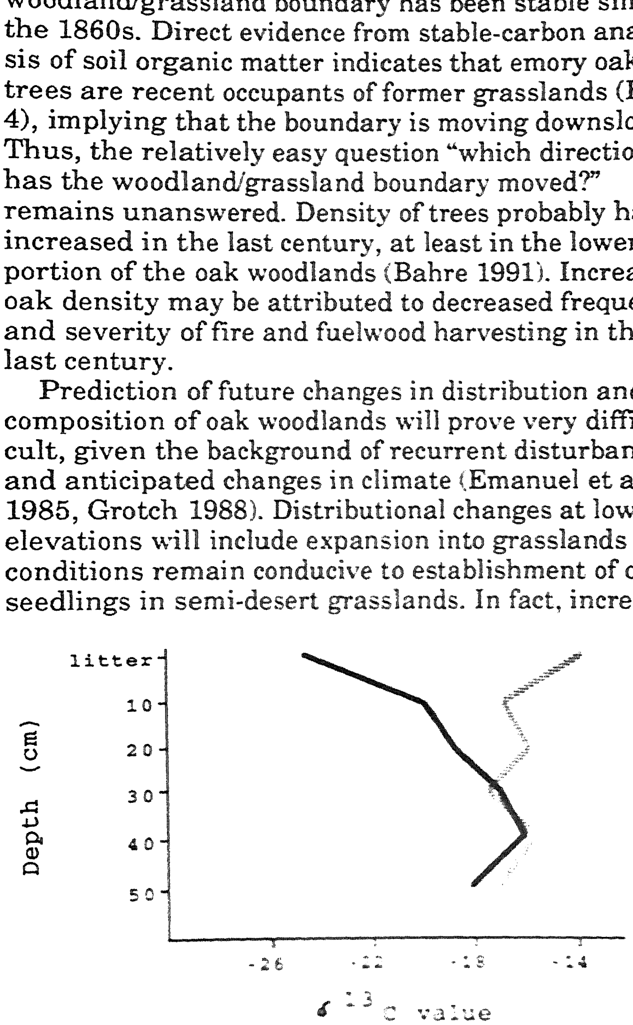

Figure 4. Mean ^{13}C values of litter and soil organic matter under emory oak trees (solid line) and in the grassland phase (dashed line) of an emory oak savanna in southern Arizona. ^{13}C values reflect the photosynthetic pathway of plants from which organic matter was derived: values near -14 indicate C_4 plants (i.e., warm-season grasses), whereas more negative values indicate C_3 plants (i.e., oak trees). The stable C_4-like signature throughout the grassland soil profile, coupled with a shallow C_3-like signature under trees, indicates that emory oak trees are recent occupants of this former grassland.

ing atmospheric CO_2 may favor oaks (C_3 plants) at the expense of grasses (C_4 plants), since growth of C_3 plants often is limited by carbon fixation rate (Mooney 1991). Alternatively, increased fire frequency in semi-desert grasslands resulting from increased summer precipitation (hence, increased fine fuel) or a hotter, drier regional climate will contribute to an "upward retreat" (Hastings and Turner 1965) of oak woodlands. Distributional changes at the upper end of the oak woodland are even more difficult to predict, given the paucity of climatic correlates with species distributions.

Within the oak woodland and in adjacent communities, it seems reasonable to expect different species assemblages than we currently observe within a century. The paleoecological record clearly indicates that current communities are structurally different from those that have occurred in the past (Schoonmaker and Foster 1991). There is no reason to expect current assemblages to retain their identities if regional climate and/or disturbance regimes change significantly. Because of the rapid rate of environmental change, the restructuring of communities probably will occur at an unprecedented rate.

OPPORTUNITIES FOR FUTURE RESEARCH

Oak woodlands and savannas are among the least-studied communities in Arizona. Current understanding of the structure and function of these dryland forest systems, and the factors regulating the distribution and abundance of the plants comprising them, is extremely limited. We have hardly advanced beyond descriptions of community structure, and these descriptions often are too general to be useful for appropriate management. Gaps in our knowledge of the autecology and synecology of these woodlands presently constrain the ability to predict and anticipate their responses to disturbance, manipulation, and management. Fundamental research focusing on the life history of individual plants and populations and their organization into communities will facilitate the development of predictable outcomes to management strategies.

Because these woodlands have received little scientific attention, avenues for future ecological research are nearly limitless. For example, root morphology, production, and turnover rates have not been described for any of these oak species. Nyandiga and McPherson (1992) indicated that further research is needed on effects of water potential fluctuations on acorn germination, effects of acorn maturity stage and size on germinability, and evolutionary and taxonomic relations of semi-arid and warm-temperate oak species. In addition, knowledge of species life-histories (e.g., patterns and rates of seedling establishment), plant-soil interactions, overstory-understory relations, community successional pathways, historical (and pre-historical) changes in species distributions, and spatial relations are fundamental to understanding the effects of disturbance, manipulation, and management on woodland systems. Future research that focuses on manipulative experiments will maximize usefulness to resource managers and make the greatest contribution to development of ecological theory.

LITERATURE CITED

Aikman, J.M. 1934. The effect of low temperature on germination and survival of native oaks. Proceedings of the Iowa Academy of Science 14:89-93.

Archer, S., C. Scifres, and C.R. Bassham. 1988. Autogenic succession in a subtropical savanna: conversion of a grassland to thorn woodland. Ecological Monographs 58:111-127.

Axelrod, D.I. 1958. Evolution of the Madro-Tertiary geoflora. Botanical Review 24:433-509.

Bahre, C.J. 1977. Land-use history of the Research Ranch, Elgin, Arizona. Journal of the Arizona Academy of Science 12 (supplement 2):1-32.

Bahre, C.J. 1985. Wildfire in southeastern Arizona between 1859 and 1890. Desert Plants 7:190-194.

Bahre, C.J. 1991. A Legacy of Change. University of Arizona Press, Tucson. 231 p.

Bahre, C.J. and C.F. Hutchinson. 1985. The impact of historical fuelwood cutting on the semidesert woodlands of southeastern Arizona. Journal of Forest History 29:175-186.

Baisan, C.H. and T.W. Swetnam. 1990. Fire history on a desert mountain range: Rincon Mountain Wilderness, Arizona, U.S.A. Canadian Journal of Forest Research 20:1559-1569.

Barton, A.M. 1991. Factors controlling the elevational positions of pines in the Chiricahua Mountains, Arizona: drought, competition, and fire. Ph.D. dissertation, University of Michigan, 162 p.

Bennett, R.J. 1977. The effect of burial by squirrels on germination and survival of oak and hickory nuts. American Midland Naturalist 98:319-329.

Bennett, P.S. and M.R. Kunzmann. 1992. The applicability of generalized fire prescriptions to burning of Madrean evergreen forest and woodland. Journal of Arizona-Nevada Academy of Science 24-25:79-84.

Betancourt, J.L., T.R. Van Devender, and P.S. Martin. 1990. Packrat Middens: the Last 40,000 Years of Biotic Change. University of Arizona Press, Tucson. 467 p.

Bewley, J.D. and M. Black. 1982. Physiology and Biochemistry of Seeds, Volume 2. Springer-Verlag, Berlin. 375 p.

Blackburn, W.H. and P.T. Tueller. 1970. Pinyon and juniper invasion in black sagebrush communities in east-central Nevada. Ecology 51:841-848.

Bogusch, E.R. 1951. Brush invasion on the Rio Grande Plains of Texas. Texas Journal of Science 4:85-90.

Borchert, M.I., F.W. Davis, J. Michaelsen, and L.D. Oyler. 1989. Interactions of factors affecting seedling recruitment of blue oak (*Quercus douglasii*) in California. Ecology 70:389-404.

Borelli, S. 1990. Natural regeneration of oak woodlands of southeastern Arizona: a survey. M.S. thesis. University of Arizona, Tucson. 54 p.

Brown, D.E. 1982. Biotic communities of the American southwest-United States and Mexico. Desert Plants 4:1-342.

Bucher, E.H. 1987. Herbivory in arid and semi-arid regions of Argentina. Revista Chilenda de Historia Natural 608:265-273.

Cable, D.R. 1957. Recovery of chaparral following burning and seeding in central Arizona. USDA Forest Service Research Note 28. Rocky Mountain Experiment Station, Fort Collins, Colorado. 6 p.

Callaway, R.M., N.M. Nadkarni, and B.E. Mahal. 1991. Facilitation and interference of *Quercus douglasii* on understory productivity in central California. Ecology 72:1484-1499.

Clark, R.G. 1983. Threshold requirements for fire spread in grassland fuels. Ph.D. dissertation, Texas Tech University, Lubbock. 72 p.

Collins, D.C. 1989. Timberland and woodland resources outside National Forests in Arizona, 1985. USDA Forest Service Resource Bulletin INT-66. Intermountain Research Station, Ogden, Utah.

Emanuel, W.R., H.H. Shugart, and M.P. Stevenson. 1985. Climatic change and the broad-scale distribution of terrestrial ecosystem complexes. Climatic Change 7:29-43.

Everett, R.L., S.H. Sharrow, and R.O. Meeuwig. 1983. Pinyon-juniper woodland understory distribution patterns and species association. Bulletin of the Torrey Botanical Club 110:454-463.

Farmer, R.E. 1977. Epicotyl dormancy in white and chestnut oaks. Forest Science 23:329-332.

Goldberg, D.E. 1982. The distribution of evergreen and deciduous trees relative to soil types: an example from the Sierra Madre, Mexico, and a general model. Ecology 63:942-951.

Griffin, J.R. 1971. Oak regeneration in the upper valley, California. Ecology 52:862-415.

Griffin, J.R. 1976. Regeneration in *Quercus lobata* savannas, Santa Lucia Mountains, California. American Midland Naturalist 95:422-435.

Grotch, S.L. 1988. Regional intercomparisons of general circulation model predictions and historical climate data. U.S. Department of Energy Publication DOE/NBB-0084, Washington, D.C. 291 p.

Harrington, G.N., A.D. Wilson, and M.D. Young. 1984. Management of Australia's Rangelands. CSIRO, Melbourne.

Hastings, J.R. and R.M. Turner. 1965. The Changing Mile. University of Arizona Press, Tucson. 317 p.

Haworth, K. 1992. Effects of *Quercus emoryi* on microclimate and herbaceous biomass in a semi-arid savanna. M.S. thesis, University of Arizona. 114 p.

Johnson, D.E., H.A.M. Mukhtar, R. Mapston, and R.R. Humphrey. 1962. The mortality of oak-juniper woodland species following a wild fire. Journal of Range Management 15:201-205.

Juhnel, H. 1957. Effects of height on germination of forest tree seed. Proceedings of the International Seed Testing Association 26:437-452.

Kearney, T.H. and R.H. Peebles. 1960. Arizona Flora, second edition. University of California Press, Berkeley. 1085 p.

Kelly, R.D. and B.H. Walker. 1976. The effects of different forms of land use on the ecology of a semi-arid region of southeastern Rhodesia. Journal of Ecology 64:553-576.

Korstian, F. 1927. Factors controlling germination and early survival in oaks. Yale University School of Forestry Bulletin 19. 115 p.

Marshall, J.T., Jr. 1957. Birds of the pine-oak woodland in southern Arizona and adjacent Mexico. Pacific Coast Avifauna Number 32, Cooper Ornithological Society, Berkeley, California. 125 p.

Marshall, J.T., Jr. 1963. Fire and birds in the mountains of southern Arizona. Tall Timbers Fire Ecology Conference 2:135-141.

McClaran, M.P. and J.W. Bartolome. 1989a. Effect of *Quercus douglasii* (Fagaceae) on herbaceous understory along a rainfall gradient. Madrono 36:141-153.

McClaran, M.P. and J.W. Bartolome. 1989b. Fire-related recruitment in stagnant *Quercus douglasii* populations. Canadian Journal of Forest Research 19:580-585.

McClaran, M.P. and J.W. Bartolome. 1990. Comparison of actual and predicted blue oak age structures. Journal of Range Management 43:61-63.

McCreary, D.D. 1989. Regenerating native oaks in California. California Journal of Agriculture 43(1):4-6.

McPherson, G.R. and H.A. Wright. 1988. Patterns of shrub invasion in semi-arid grasslands. American Midland Naturalist 120:391-397.

McPherson, G.R., G.A. Rasmussen, D.B. Wester, and R.A. Masters. 1991. Vegetation and soil zonation associated with *Juniperus pinchotii* Sudw. trees. Great Basin Naturalist 51:316-324.

Meyer, J.W. 1988. First year coppice regeneration of *Quercus emoryi* and *Quercus arizonica* in the Huachuca Mountains, Arizona. M.S. thesis, University of Arizona, Tucson. 55 p.

Miller, H.A. and S.H. Lamb. 1985. Oaks of North America. Naturegraph Publishers, Inc., Happy Camp, California. 327 p.

Mooney, H.A. 1991. Biological response to climate change: an agenda for research. Ecological Applications 1:112-117.

National Oceanic and Atmospheric Administration. 1989. Climatological Data Annual Summary, Arizona 1989. Volume 93, Number 13. National Climatic Data Center, Asheville, North Carolina.

Niering, W.A. and C.H. Lowe. 1984. Vegetation of the Santa Catalina Mountains: community types and dynamics. Vegetatio 58:3-28.

Nyandiga, C.O. 1991. Storage and germination of *Quercus emoryi* and *Quercus arizonica* acorns. M.S. thesis, University of Arizona, Tucson. 73 p.

Nyandiga, C.O. and G.R. McPherson. 1992. Germination of two warm-temperate oaks, *Quercus emoryi* and *Quercus arizonica*. Canadian Journal of Forest Research 22:*in press*.

Pase, C.P. 1965. Shrub seedling regeneration after controlled burning and herbicidal treatment of dense pringle manzanita chaparral. USDA Forest Service Research Note RM-56. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. 2 p.

Pase, C.P. 1969. Survival of *Quercus turbinella* and *Q. emoryi* seedlings in an Arizona chaparral community. Southwestern Naturalist 14:149-156.

Sanchini, P.J. 1981. Population structure and fecundity patterns in *Quercus emoryi* and *Q. arizonica* in southeastern Arizona. Ph.D. dissertation, University of Colorado, Boulder. 149 p.

Schoonmaker, P.K. and D.R. Foster. 1991. Some implications of paleoecology for contemporary ecology. Botanical Review 57:204-245.

Schopmeyer, C.S. 1974. Seeds of woody plants in the United States. USDA Forest Service Agriculture Handbook No. 450, Washington, D.C. 883 p.

Shaw, M.W. 1968. Factors affecting the natural regeneration of sessile oak in North Wales: preliminary study of acorn production, viability and loss. Journal of Ecology 56:563-583.

Singh, J.S. and M.C. Joshi. 1979. Ecology of the semiarid regions of India with emphasis on land-use. Pp. 243-273 in (B.H. Walker, ed.) Management of Semi-Arid Ecosystems. Elsevier, Amsterdam.

Snow, G.E. 1972. Some factors controlling the establishment and distribution of *Quercus agrifolia* Nee. and *Quercus engelmanii* Greene. in certain southern California oak woodlands. Ph.D. dissertation, Oregon State University, Corvallis, Oregon. 105 p.

Standiford, R., N. McDougland, R. Phillips, and A. Nelson. 1991. South Sierra oak regeneration weak in sapling stage. California Journal of Agriculture 45(2):12-14.

Swetnam, T.W., C.H. Baisan, P.M. Brown, and A.C. Caprio. 1989. Fire history of Rhyolite Canyon, Chiricahua National Monument. Technical Report 32, USDI National Park Service Cooperative Park Studies Unit, Tucson, Arizona.

Touchan, R. 1986. Growth and yield of emory oak woodlands in southeastern Arizona. M.S. thesis, University of Arizona, Tucson. 36 p.

Touchan, R. 1991. Effects of coppice thinning on growth and yield of emory oak sprouts in southeastern Arizona. Ph.D. dissertation, University of Arizona, Tucson. 130 p.

United States Department of Agriculture, Forest Service. 1985. Arizona Forest Survey field procedures. Intermountain Research Station, Ogden, Utah.

van Vegten, J.A. 1983. Thornbrush invasion in a savanna ecosystem in eastern Botswana. Vegetatio 56:3-7.

Vogt, A.R. 1974. Physiological importance of change in endogenous hormones during red oak stratification. Forestry Science Bulletin 20:187-191.

Walker, B.H. and J.-C. Menaut (eds). 1988. Research procedure and experimental design for savanna ecology and management. CSIRO, Melbourne, Australia.

Wallmo, O.C. 1955. Vegetation of the Huachuca Mts., Arizona. American Midland Naturalist 54:466-480.

White, K.L. 1966. Structure and composition of foothill woodland in central California. Ecology 47:229-237.

Whittaker, R.H. and W.A. Niering. 1964. Vegetation of the Santa Catalina Mountains, Arizona. I. Ecological classification and distribution of species. Journal of the Arizona Academy of Science 3:9-34.

Whittaker, R.H. and W.A. Niering. 1965. Vegetation of the Santa Catalina Mountains, Arizona. II. A gradient analysis of the south slope. Ecology 46:429-452.

Wright, H.A. and A.W. Bailey. 1982. Fire Ecology: United States and southern Canada. John Wiley & Sons, New York. 501 p.

Growth, Yield, and Utilization of Oak Woodlands in the Southwestern United States[1]

Peter F. Ffolliott and Gerald J. Gottfried[2]

Abstract.–Growth rates and subsequent yields of oak woodlands in the southwestern United States are comparatively low. Frequent occurrence of multiple-stemmed, irregularly-formed trees limit widespread, commercial utilization for wood products, although fuelwood and fenceposts are harvested for largely local uses. More intensive inventories are necessary to manage these woodlands in terms of conservation and sustainable production.

Source information to describe stand, stocking, and growth characteristics of oak woodlands in the southwestern United States is limited. Tree densities generally vary from scattered individuals to several hundred stems per acre. Volumes range from less than 100 to over 500 cubic feet per acre. Small, often multiple-stemmed, irregularly-formed trees frequently are found in oak woodland communities. Inherently low growth rates and, as a result, long rotational cycles between harvests, and poor form of trees largely preclude widespread, commercial utilization of the woodlands for wood products.

Nevertheless, pressures to meet growing demands for fuelwood, fenceposts, and other wood products from oak woodlands have been growing. In 1984, for example, over 50,000 cords of oak were cut in Arizona, accounting for about 25% of the total fuelwood harvest (McLain 1988). This survey did not indicate whether the oak was harvested from Gambel oak (*Quercus gambelii*) sites, encinal oak woodlands, or other woodlands, however. The USDA Forest Service and other land management agencies have become concerned about long-term sustainability of oak resources and, therefore, have been restricting the number and amounts of fuelwood sales in the southwestern United States. There also are environmental considerations, because oak is valuable for wildlife food and habitats, recreation and tourism, and a range of other non-consumptive uses.

Knowledge of growth, yield, and utilization potentials is critical if environmentally-sound, sustainable management practices are to be planned and implemented in oak woodlands. Although there is little information on growth, yield, and utilization of oak woodlands in comparison to more commercially valuable forest types, this paper reviews the availabl information.

GROWTH AND YIELD

Growth and yield of oak woodlands in the southwestern United States is low in comparison to that found in higher elevation montane forest types (Ffolliott 1988). Inventories describing growth rates and subsequent yields of oak woodlands are few in number. However, some estimates that have been made are presented below. Simulation methods to estimate growth and yield of oak woodlands also are described.

FIA Estimates

Forest Inventory and Analysis (FIA), formerly the Forest Survey of the USDA Forest Service, inventories renewable forest, woodland, and rangeland resources of the United States on a continuing basis (USDA Forest Service 1987a). These inventories are undertaken in response to state, regional, and national informational needs, largely for policy resolutions. Information on extent, conditions, and locatio of Arizona's oak type is presented in a report published recently by FIA on renewable resources in the State (Conner et al. 1990). Statistical summaries of area by land classes, ownership, volume, and growt and mortality were included in this report. Excerpts from this report are presented below to illustrate the kinds of information available on growth and yield estimates.

The oak type in Arizona, lands where oak species dominate but other tree species also occur, encompasses 888,756 acres (Conner et al. 1990). Approximately 50% of the oak type is found on National Forest lands and 40% on private lands, with the latter category including Indian lands. About 92% o the oak type has been classified as high site lands. High site lands are those capable of producing wood products (fuelwood, fenceposts, etc.) on a sustainable basis. A low site classification is used to exclude unusable areas and volumes from calculations of allowable harvest levels. Some wood on low site lands might be used on a one-time basis, although amounts of wood harvested would be insignificant.

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There are two main oak woodlands in the southwestern United States. Areas dominated by Gambel oak are found in the oak type of central and northern Arizona. In the southeastern part of the State, the oak type includes Arizona white oak (*Q. arizonica*), Emory oak (*Q. emoryi*), Mexican blue oak (*Q. oblongifolia*), and silverleaf oak (*Q. hypoleucoides*). The latter group of tree species is common to the western live oak cover type (Ffolliott 1980), generally referred to as oak woodlands of the southwestern United States in this symposium.

Oak woodlands often contain minor components of pinyon, junipers, and other tree species and, as a consequence, these volumes are included in this paper. Oak trees are components of some ponderosa pine (*P. ponderosa*) and mixed conifer habitat types (USDA Forest Service 1987b), although these situations are not considered here. Data summaries presented also do not include estimates of growth and yield of timber species, such as ponderosa pine, which occur in some oak woodlands.

It is difficult to isolate estimates of volume, growth, and mortality for oak woodlands of southeastern Arizona from estimates for oak woodlands elsewhere in the State without referring to baseline data sets of the inventory. Nevertheless, estimates presented in the FIA report provide indications of orders-of-magnitude for values of growth and yield of oak woodlands in the southwestern United States.

Total net (live) volume in the oak type, that is, gross cubic-foot volume in the merchantable portion of trees less deductions for cull volume, was 397.2 million cubic feet in 1985, the year of data collections (Conner et al. 1990). Over 97% of this volume was located on high site lands. This volume translated into an average of 473 cubic feet per acre. Volume on low site lands was only 141 cubic feet per acre.

Forty-eight percent of the net volume in oak woodlands occurs on sites which support over 1,000 cubic feet per acre. Oak woodlands average about 512 cubic feet of live and dead materials per acre, varying by site and species compositions (Conner et al. 1990). Dead material, especially dead branches of live trees, often accounts for 10 to 15% of the total volume on an area. Net dead volume, which is the total net volume of dead trees plus net volume of dead material on live trees, is estimated at 58.3 million cubic feet. In addition to the volume in the oak type, nearly 519.4 million cubic feet of oak live volume is associated with other forest and woodland types.

Net annual growth of the oak type, or gross annual growth minus average annual mortality, was 4,169,000 cubic feet. Ninety-nine percent of this growth was found on high site lands. On a per acre basis, net annual growth was 5.03 cubic feet on high site lands, or equivalent to about 1% of the net (live) volume. Net annual growth on low site lands was less than 1 cubic-foot per acre. Mortality generally was low, reducing net annual growth estimates by only 1%. Conner et al. (1990) indicated that one reason for low mortality likely was the long history of utilization in some areas, which has reduced the number of over-mature trees.

Estimates of volume, growth, and mortality of the oak type in Arizona were compiled through use of appropriate volume equations and factors (Chojnacky 1988a, Chojnacky 1988b). Percent standard estimates for volume, growth, and mortality were ±3.7, ±5.9, and ±30.2, respectively.

FIA personnel currently are preparing a report on renewable resources in New Mexico, that also will present information on extent, conditions, and location of the oak type. This report is scheduled for publication in 1992 (Van Hooser, in preparation). Other reports prepared by FIA in which estimates of growth and yield of oak types in the southwestern United States are presented include those of timberland and woodland resources on lands outside of the National Forests in Arizona (Collins 1989) and New Mexico (Van Hooser 1990).

Other Estimates of Growth and Yield

Touchan (1986, 1988) obtained estimates of number of trees, volume, and growth in a study of growth and yield of Emory oak in the San Rafael Valley of southeastern Arizona. Stands sampled included those in which fuelwood had been harvested 2 and 9 years earlier, an area cabled 20 years before the study, and a natural (uncut) area. Per acre estimates in these stands varied with past management histories. Numbers of trees ranged from less than 115 (in the stand harvest 2 years earlier) to over 800 (in the stand harvested 9 years before), merchantable volume from about 120 (in the natural area) to almost 185 (in the area cabled 20 years ago) cubic feet, and annual growth from nearly 4.9 (in the natural area) to about 15.0 (in the area cabled 20 years before the study) cubic feet per acre.

Although site-specific, these estimates are indicative of effects of management practices on sustainability of wood production in oak woodlands of southeastern Arizona. It must be noted, however, that volumes reported in this study were estimated with use of a composite volume table developed for use elsewhere (Gevorkiantz and Olson 1955). In addition, growth estimates were obtained through applications of a stand table projection method and represent estimates of gross annual growth. As a consequence, estimates of growth and yield reported cannot be compared directly to those reported in the FIA inventories.

Simulation Techniques

Simulation techniques have been and continue to be developed to estimate growth and yield of oak woodlands in the southwestern United States, especially in reference to obtaining estimates of growth and yield for stand-level management planning purposes. Simulators that are available fall into two categories. Variable-density tables have been used to simulate in even-aged stand structures, while stand table projection methods have been used in uneven-aged stand structures. Differentiation between even-aged and uneven-aged structures is arbitrary, although the definition presented by the Society of American Foresters (1971) generally applies. Even-aged stands are those in which trees do not differ by more than 10 to 20 years. Uneven-aged stands are those where age differences are greater than these limits, or where three or more age classes are represented.

Variable-density yield tables, in which stand density (in this case, basal area) is used as an independent variable with stand age and site index (Callison 1988, 1989) to estimate the growth and yield, have been developed for application in even-aged stands in oak woodlands of the southwestern United States (Fowler 1990). These variable-density yield tables are represented by a set of equations to estimate current and then future yields, with the difference between these two estimates being a prediction of net growth for the period in consideration. Approximations of rotation ages also can be obtained. A description of these variable-density yield tables, including method of construction and their application, is presented elsewhere in these proceedings.

A simulation model based on a stand table projection method has been developed to estimate impacts of management practices on growth and yield of uneven-aged oak woodland stands in the southwestern United States (Ffolliott and Guertin 1988, Ffolliott et al. 1988). The model is based largely upon gross changes in number of trees per acre in 2-inch dbh classes for a growth projection period. It is an interactive model, which allows a user to respond directly to a set of statements and questions. Depending upon the nature of the simulation exercise, estimates can be obtained for current (initial) management conditions; at user selected times in the future, again, under current (initial) management conditions; or after implementation of alternative management practices.

Simulation options in the model involve applications of a simplified version of TRAS (Timber Resource Analysis System), a widely used computer program for projection of forest resources in the United States (Alig et al. 1982, Larson and Goforth 1970).

UTILIZATION

Utilization of tree species in oak woodlands has been restricted largely to fuelwood and fenceposts. However, trees in these woodlands represent a wood fiber resource that could be used, from a technical feasibility viewpoint, in manufacturing wood products such as charcoal (Barger and Ffolliott 1972), although marketing opportunities are limited at present. Wood products that can be made from smaller, irregular stems offer additional utilization opportunities.

Fuelwood

Trees in oak woodlands have been utilized longer and more intensively for fuelwood than any other wood product. Wood continues to be a principal fuel used in many homes in the region, with this use increasing in recent years. Heat content, ignition, and burning characteristics are among the more important basic fuel characteristics. Judged by these criteria, oak makes excellent fuelwood.

Volumes of fuelwood that have been harvested in oak woodlands are difficult to estimate, although the USDA Forest Service issues permits for harvesting of specified amounts of fuelwood in some instances. In addition, it is difficult to quantify volumes of fuelwood that are cut in terms of species preference. However, due to their accessibility to fuelwood cutters, Emory and Arizona white oaks often are favored in the southern part of the region, while Gambel oak is favored in the northern part.

Conner et al. (1990) indicated that a large sustained increase in fuelwood demands could cause local shortages in accessible materials and, as a result, drain total supply. Therefore, some managers have begun limiting amounts of fuelwood individuals can harvest for personal use and excluding commercial operations.

Fenceposts

Some of the tree species in oak woodlands are utilized for fenceposts. In general, their availability and durability features are primary reasons for this use (Barger and Ffolliott 1972). Large numbers of fenceposts were cut for local use during early periods of settlement. However, increased use of preservative-treated wooden and steel posts has curtailed markets for oak fenceposts in recent years. Harvesting fenceposts is a selective operation, since only those stems meeting specified size and form requirements can be utilized.

Sawn Products

Trees in oak woodlands have not been utilized widely for sawn products, due largely to their relatively small size and poor form. Nevertheless, in other regions of North America in which woodland communities are found, railroad ties and mine timbers have been cut on limited scales (Barger and Ffolliott 1972). Oaks occasionally are cut into lumber by smaller mills.

Other Potentials for Utilization

Charcoal manufacture through carbonization is an example of chemical alteration to obtain a wood product. Many of the tree species in oak woodlands are suited to production of charcoal (Barger and Ffolliott 1972), although large markets are not available at this time. All wood is about 50% carbon and, consequently, charcoal yields are proportional to the density of the wood. Therefore, denser tree species, such as oak, are preferred for charcoal, since yields in terms of volume are greater.

There recently has been interest in using local oak to manufacture specialty furniture in the southwestern United States. Development of this industry could be relatively lucrative to communities located adjacent to the oak woodlands.

Opportunities for expanding utilization of oak in the southwestern United States and northern Mexico depend largely upon physical and chemical properties of the wood itself. Work to learn more of these properties and their respective variabilities is continuing. To illustrate this point, characterizations of specific gravity and estimated physical properties of Emory oak in southeastern Arizona is reported elsewhere in these proceedings.

CONCLUSIONS

Wood production likely will not be the primary function for oak woodlands in the southwestern United States. Inherently low levels of growth and yield, and lack of suitable markets for wood products largely limit this development. However, as indicated in papers presented in these proceedings, wildlife habitats, recreation and tourism, watershed protection, and ongoing environmental issues in the region have heightened pressures to ensure that each of these other uses is given its due consideration.

More intensive stand-level inventories of oak woodlands, from which estimates of growth, yield, and mortality values can be obtained for management planning purposes, are necessary. This information is prerequisite if oak woodlands are not to be "mined," as frequently encountered in the past, but "managed" in terms of conservation and sustainable production. Information obtained from these inventories should indicate feasibilities of increased utilization for wood products, for example, for charcoal, flooring, and furniture manufacturing. Inventories also should be linked to vegetation-soils maps and habitat types to spatially delineate productive areas for management and sensitive areas for protection.

LITERATURE CITED

Alig, R. J., G. E. Brink, M. H. Goforth, V. J. LaBau, and T. J. Mills. 1982. TRAS-1980: User's manual for an expanded version of the TRAS projection systems. USDA Forest Service, 63 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Barger, R. L., and P. F. Ffolliott. 1972. Physical characteristics and utilization of major woodland tree species in Arizona. USDA Forest Service Research Paper RM-83, 80 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Callison, J. C. 1988. Site quality indices for Emory oak. p. 39-43. *In* Ffolliott, P. F., and J. D. Hasbrouck. (eds.) Oak woodland management: Proceedings of the workshop. [Sierra Vista, Ariz., April 12-13, 1988] School of Renewable Natural Resources, University of Arizona, 88 p. Tucson, Arizona.

Callison, J. C. 1989. Site quality indices for the Emory oak woodlands of southeastern Arizona. PhD Dissertation, 38 p. University of Arizona, Tucson, Arizona.

Chojnacky, D. C. 1988a. Juniper, pinyon, oak, and mesquite volume equations for Arizona. USDA Forest Service Research Paper INT-391, 11 p. Intermountain Research Station, Ogden, Utah.

Chojnacky, D. C. 1988b. Woodland volume equations for Arizona Fort Apache and San Carlos Indian Reservations. USDA Forest Service Research Note INT-379, 7 p. Intermountain Research Station, Ogden, Utah.

Collins, D. C. 1989. Timberland and woodland resources outside National Forests in Arizona, 1985. USDA Forest Service Resource Bulletin INT-66, 61 p. Intermountain Research Station, Ogden, Utah.

Conner, R. C., J. D. Born, A. W. Green, and R. A. O'Brien. 1990. Forest resources of Arizona. USDA Forest Service Resource Bulletin INT-69, 92 p. Intermountain Research Station, Ogden, Utah.

Ffolliott, P. F. 1980. Western live oak. p. 118. *In* Eyre, F. H. (ed.) Forest cover types of the United States and Canada. 148 p. Society of American Foresters, Washington, DC.

Ffolliott, P. F. 1988. Arid zone forestry program: State of knowledge and experience in North America. Technical Bulletin 264, 80 p. Arizona Agricultural Experiment Station, Tucson, Arizona.

Ffolliott, P. F., and D. P. Guertin. 1988. Simulation of growth and yield in oak woodlands for management purposes. p. 19-25. *In* Ffolliott, P. F., and J. D. Hasbrouck. (eds.) Oak woodland management: Proceedings of the workshop. [Sierra Vista, Ariz., April 12-13, 1988] School of Renewable Natural Resources, University of Arizona, 88 p. Tucson, Arizona.

Ffolliott, P. F., W. O. Rasmussen, and D. P. Guertin. 1988. STAND: An interactive model to simulate the growth and yield of woodlands in the Southwest. p. 968-975. *In* Ek, A. R., S. R. Shifley, and T. E. Burk. (eds.) Forest growth modelling and prediction: Proceedings of the IUFRO conference. [Minneapolis, Minnesota, August 23-27, 1987] USDA Forest Service General Technical Report NC-120, 1,149 p. North Central Forest Experiment Station, St. Paul, Minnesota.

Fowler, W. P. 1990. Variable-density yield tables for Emory oak of southeastern Arizona. PhD Dissertation, 73 p. University of Arizona, Tucson, Arizona.

Gevorkiantz, S. R., and L. P. Olson. 1955. Composite volume tables for timber and their application in the Lake States. Technical Bulletin 1104, 51 p. U.S. Department of Agriculture, Washington, DC.

Larson, R. W., and M. H. Goforth. 1970. TRAS: A computer program for the projection of timber volume. Agriculture Handbook 377, 24 p. U.S. Department of Agriculture, Washington, DC.

McLain, W. H. 1988. Arizona's 1984 fuelwood harvest. USDAS Forest Service Resource Bulletin INT-57, 8 p. Intermountain Research Station, Ogden, Utah.

Society of American Foresters. 1971. Terminology of forest science, technology, practices and products. 349 p. W. Heffer and Sons, Ltd., Cambridge, England.

Touchan, R. 1986. Growth and yield of Emory oak woodlands in southeastern Arizona. Master's Thesis, 36 p. University of Arizona, Tucson, Arizona.

Touchan, R. 1988. Growth and yield of Emory oak. p. 11-18. *In* Ffolliott, P. F., and J. D. Hasbrouck. (eds.) Oak woodland management: Proceedings of the workshop. [Sierra Vista, Ariz., April 12-13, 1988] School of Renewable Natural Resources, University of Arizona, 88 p. Tucson, Arizona.

USDA Forest Service. 1987a. Forest Service resource inventory: An overview. Forest Inventory and Economics Research, 29 p. USDA Forest Service, Washington, DC.

USDA Forest Service. 1987b. Forest and woodland habitat types (plant associations) of Arizona south of the Mogollon Rim and Southwestern New Mexico. USDA Forest Service, Southwestern Region, Albuquerque, New Mexico.

Van Hooser, D. D. 1990. Timberland and woodland resources outside National Forests in New Mexico, 1987. USDA Forest Service Resource Bulletin INT-68, 72 p. Intermountain Research Station, Ogden, Utah.

Van Hooser, D. D., R. A. O'Brien, and C.C. Collins. 1992. New Mexico's forest resources. USDA For. Serv. Resource Bull. INT-XXX. XX p.

Ecology of Oak Woodlands in the Sierra Madre Occidental of Mexico[1]

Victor Manuel Hernandez C., Francisco Javier Hernandez, and Santiago Solis Gonzales[2]

INTRODUCTION

The oak woodlands (*Quercus* spp.) are found in all Mexico, except the Yucatan State. The quercus genus is characterized by having a wide adaptation variability, and it can be found in temperate, subtropical tropical, and semidesertic regions as dominant or complementary species in association with other wood species.

Mexico is well known as a country with a very high biodiversity, and the Mexican forests have different pine-oak associations. With more than 200 species of classified oaks (Bejar, H.G. 1982); however, the precise number of oak species in Mexico is not exactly known.

The quercus species are classified in five subgenus, and three subgenus had been documented in México: The erytrobalanus or red oaks, composed by 53 species which represent 49% of the known quercus species. Lepidobalanus or white oaks, with 52 identified species. And the intermediate oaks (red-white oaks), the smallest group with 3 known oak species that correspond to the protobalanus and represent 3% of the identified oaks in México (Zavala Ch. F. 1991). This subgenus has small distribution in North Baja California and close islands, and it is considered the transition group between the leucobalanus and erytrobalanus (Valdez, T.V. and Aguilar, e. Ma. L. 1983). At the present time, leucobalanus and ciclobalanus have not been documented in the mexican forests.

OAK DISTRIBUTION IN MEXICO

Some oak species can be found in a wide range, growing in many Mexican states; meanwhile, other species grow in different environmental conditions within the same state. Other endemic species grow in special environmental conditions.

Some examples of oak species that have a wide range of variability are: *Quercus rugosa*, a white oak documented in 22 Mexican states. And the red oaks *Q. castanea*, *Q. candicans*, and *Q. laurina*, grow in 20, 18 and 17 states, respectively. *Q. laeta*, classified as white oak can be found in 16 states. At the same time, *Q. crassifolia* and *Q. obtusata*, a red oak and white oak, respectively are represented in 15 states.

Zavala Ch. F. (1991) describes the following species which grow in only one state: *Q. agrifolia* exists in Baja California. The *Q. benthami*, *Q. bogueronae* and *Q. crispifolia* can be found in Chiapas State. The environmental conditions in Nuevo León State are adequate to grow *Q. cupreata* and *Q. durani*, *Q. ondulata* exists in Coahuila State; and *Q. ocarpa* is found in Jalisco State.

Q. brandegei, *Q. devia* and *Q. cendrocencis* are found in Baja California Sur. *Q. duratifolia*, *Q. monserratensis* and *Q. paxtalensis* are documented as endemic species of Chiapas State.

In contrast, some states exhibit a great variability of oak species. For example, Jalisco State has the highest species diversity. It has been determined that this state have environmental conditions to grow 41 oak species. Michoacan State follows in number of species with 31 oak species. the states of Durango and Veracruz have 30 and 28 oak species respectively. In each one of the states of Chiapas, México, Hidalgo and San Luis Potosi exist 26 oak species.

Studies in Nuevo León and Oaxaca states reported 25 oak species. And the states with more than 20 oak species documented are Chihuahua, Puebla, Guerrero and Sonora. In contrast, the states of Tabasco, Campeche and Quintana Roo have only *Q. Oleoides* (white oak). At the same time in the state of Tlaxacala has been found 7 oak species.

Zavala, Z.R. (1991) mentions that in Durango state the most common oaks species are *Q. arizonica*, *Q. intrincata*, *Q. crassifolia*, *Q. hartwegii*, *Q. chihuahuensis*, *Q. cordifolia*, *Q. grisea*, *Q. emory* and *Q. juniperus*. These species are associated with pine species such as: *Pinos cooperi*, *P. duranguensis*, *P. chihuahuana*, *P. teocote*, *P. leiophyla*, *P. engelmanii*, *P. herrerai*, *P. cembroides*, among other species.

CLIMATE AND SOIL CONDITIONS OF OAK WOODLANDS

The soil where these species are established is podsolic, brown and 20-25 cms. deep. The humus is grey and the PH is strongly acid. In general, these soils have lower amounts of Nitrogen, phosphorous and potasium. In addition, Perez O. de la Paz C. (1982) mentions that in Durango are found

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Q. convallata, *Q. sideroxyla*, *Q. potosina* and *Q. obtusata* (black oak). These species exist in association with other genus such as pinus, alnus or Juniperus. These species are found at altitudes from 2400-2600. The temperature varies from 14 to 18 C. The winter is very cold, with common snow events.

The state of Michoacan is very important since the point of view of forest production. A great diversity of forest species can be found in this state. The *Quercus* Spp. that grow in this forest range are *Q. crassifolia*, *Q. candicans*, *Q. rugosa*, *Q. castanea*, *Q. obtusata*, *Q. laurina*, *Q. conspersa* and *Q. resinosa*. These oaks are found in mixed stands or pure stands. The *P. michoacana*, *P. pseudostrobus*, *P. douglasiana*, *P. lawsonii*, *P. pringley*, *Alnus firmifolia*, *Carpinus caroliniana*, *Clethra mexicana*, *Arbutus xalapensis*, *Acacia pennatula* and other species. The soils where this species are growing are volcanic andosols and podsolic, with 6.7 to 6.92 PH. The climatic conditions are semicalid and subhumid with abundant rain in the summer season. The annual precipitation mean is 1335 mm and the average temperature 16 C. The altitude is 1700 º to above 2000 º (Bello, G. MA. and Bejar M.G. 1982).

Valdez, T.V. and A. E. Ma. L. (1983) reported that in the state of Nuevo León state are established the following oak species: *Q. fulva*, *Q. gregii*, *Q. hypoxantla* and *Q. sideroxyla*. These species are found associated with *Pseudosoga* Sp. *Abies* Spp., *Juniperus* So, *cupressus* sp., *Populus* sp. and other genus. These oak species are found in other states. For example *Q. futua* is found in Nayarit, Chihuahua, Durango and Sinaloa, also *Quercus gregii* grows in Coahuila, Tamaulipas, San Luis Potosi, Durango and Hidalgo. At the same time, *Q. hipoxantha* grows in Coahuila and San Luis Potosi. *Q. sideroxila* is found in Chihuahua, Durango, Zacatecas, Aguascalientes, Guanajuato and San Luis Potosi.

These oak species grow at altitudes from 2500 to 3470 º. The mean precipitation is above to 1000 mm/year. The temperature is from 5.8 C to 10.8 C.

In summary, the high oak species diversity in Mexico requires detailed studies in order to know the best management practices for the oak woodlands nationwide.

LITERATURE CITED

Rzendowski, J. 1981. La Vegetación de México. Ed. LIMUSA, MEX. 431 pp.

Valdez, T.V. and Aguilar, M.L. 1983. El Genero Quercus en las Unidades Fisionómico-Floristicas del Municipio de Santiago, N.L.-México. Bol Técnico 67 INF-SARH; MEX. 21 pp.

Zamora, S.C. 1987. Contribución al Estudio Ecológico de los Pinso en el Estado de Chiapas. Bol Técnico 56; INF-SARH: MEX. 32 pp.

Zavala, Z.R. et al. 1982. Diagnóstico de la Industria del Aserrío del Estado de Durango. Bol. Técnico No. 87 INF-SARH; México, D.F. 86 pp.

Zavala, CH.F. 1991. Los Encinos Mexicanos: Un Recurso Desaprovechado. En Ciencia y Desarrollo Vol. XVI No. 95 (Nov-Dic-90) 43-51 pp.

The Oak and Oak-Pine Forests of Baja California Sur: Present State and Management Perspectives[1]

Laura Arriaga, Sara Diaz, and Carmen Mercado[2]

The oak and oak-pine woodlands of the Sierra de La Laguna in southern Baja California are analyzed according to their species composition, structural features and natural regeneration processes. Demographical aspects and their implications for silvicultural management are presented also for the endemic pinyon pine. Results indicate that the forest resource growing in this mountainous range does not have a timber-yielding vocation because of the small area it covers, and because of the scarcity of commercial diameters and volumes, which are insufficient to carry out a continous, and income-producing extraction of the pine resource of Baja California Sur. Lateral options of management are also discussed.

INTRODUCTION

In the southern portion of the Peninsula of Baja California lies the only mountainous range, known as the Sierra de La Laguna, that harbors oak and oak-pine woodlands of Baja California Sur. These-forests are unique in the state because they represent the only mesic vegetation surrounded by thousands of square kilometers of desert and sea. The nearest pine-oak forests on the peninsula occur to the north 800 km away in the Sierra de San Pedro Mártir, and they are separated from Mexico's continental forests by 500 km.

The Sierra de La Laguna, is part of the Cape Region, which was isolated from the rest of the continent about ten million years ago during the Miocene (Axelrod 1959). That is why the flora and fauna of the Sierra have developed unique species with insular characteristics. Brandegee (1892) reports that out of 390 genera of plants, 230 are represented by single species; the latter indicates a ratio of genera to species similar to that found in island floras (Ortega & Arriaga 1987; Arriaga & León 1989).

The Sierra de La Laguna also has a considerable socioeconomic importance, since it contains nine watersheds that receive the highest amount of rainfall in the state. Vegetation, soil, and substrate allow water storage at the subsoil, which later on is extracted by the inhabitants of the southern parts of the state.

Considering the biological importance of the mesic vegetation of Baja California Sur we characterize the present state of the oak and oak-pine woodlands that occur in the Sierra de La Laguna, and discuss some management perspectives. To achieve these aims we briefly describe the primary plant associations, their species composition, and the community structure of the woodlands growing on the highlands of the Sierra de La Laguna. Likewise we make special reference to the natural regeneration of the pine-oak forest resulting from the natural disturbance generated by treefalls, and we feature some demographical aspects of the endemic pine dominant species, *Pinus lagunae*.

STUDY SITE

The study site is at the proposed Biosphere Reserve "Sierra de La Laguna" (22°50'-24°N; 109°60'-110°10') in the upper woodlands which grow over granite and cover 51,000 hectares approximately (Villa-Salas 1968), at an altitude ranging between 1,000 and 2,200 m.a.s.l. in the Cape Region of southern Baja California, Mexico (fig. 1).

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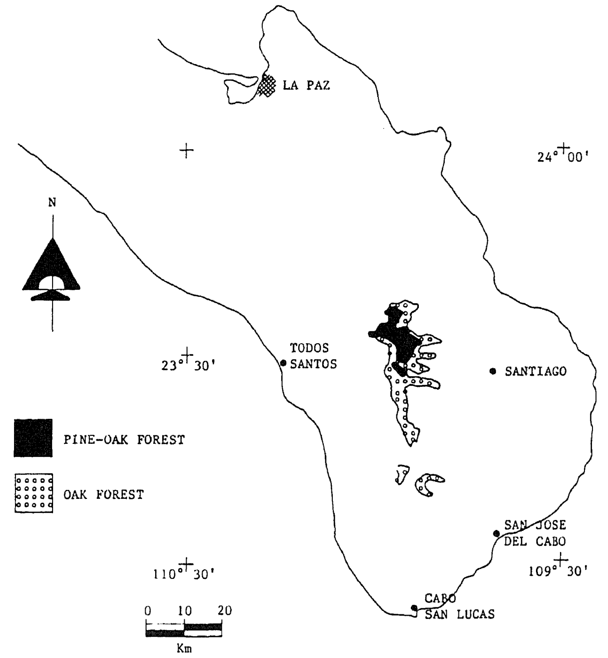

The total annual rainfall in the region, for a 15 year period is 762.3 mm. The dry season extends from November to late June, although winter rains occur heavily and periodically. The mean monthly temperature is 14.5°C. The climate corresponds to temperate humid in the classification of García (1981). The forest is greatly affected by damaging hurricanes. Twenty seven percent of the total hurricanes reaching the west coasts of Mexico during a 14 year period (1947-1961) affected the Peninsula of Baja California (Jáuregui 1967).

PRESENT STATE

Plant Communities and Species Composition

The woodlands growing on the highlands of the mountainous range are mainly oak forests and oak-pine forests. Each of this vegetation types cover an approximate area of 31,000 and 20,000 hectares, respectively (Villa-Salas 1968); although small open areas can be found, where grasslands occur.

According to the floristic records 272 species and infraspecific taxa of vascular plants have been described for the woodlands of the Sierra de La Laguna (León-de la Luz & Domínguez-Cadena 1989; León de la Luz & Coria submitted). Nearly 17% of the flora is endemic to these woodlands; while the richest families in species numbers are Gramineae, Compositae, and Leguminosae. Less diverse families are the Polypodiaceae, Cyperaceae, and Orchidaceae; while the rest of the species belong to other 60 families (León de la Luz & Domínguez-Cadena 1989).

Community Structure

The oak woodlands are more widely distributed, along the highlands of the Sierra de La Laguna, than the oak-pine forest. This spatial distribution yields different oak associations and a changing community structure that can be related to their altitudinal ubication within the mountainous range. In the northern part of the Sierra at an altitude of 700 m.a.s.l., *Quercus tuberculata* prevails as the dominant element of the forest (Table 1). This forest association presents a great intrusion of tropical trees that are also dominant such as *Lysiloma divaricata*, *Jatropha cinerea*, and *Randia megacarpa*. The latter species are typically distributed in the tropical dry forest that surrounds the oak woodlands, so the oak forest that stands at such low altitudes as in the northern part of the Sierra de La Laguna, could be considered, from a floristic and structural point of view, an ecotone between the tropical dry forest and the oak woodlands. In this locality, it can also be found *Quercus albocincta*, which has a very restricted distribution in the northern range of the Sierra.

In the oak associations that grow at higher altitudes (1,060 m.a.s.l.), in the western portion of the mountainous range, two oak species are the dominant ones, *Q. tuberculata* and *Q. devia*. Still some tropical elements subsist as dominant species within the oak forest *i.e. Erythrina flabelliformis* (Table 1). In the upper limits of distribution of the oak woodlands (1,400 m.a.s.l.), in the eastern portion of the Sierra, the dominant species that prevail here are the temperate ones.

At this altitude the oak forest is well developed from a structural and physiognomic point of view, because the climatic conditions are more mesic compared to the other sites. Finally, at the highest altitudes, (1,675 m.a.s.l.) the oaks associate with pines to constitute the oak-pine forest. The community structure of this association is also presented in Table 1, being *Quercus devia* and *Pinus lagunae* the dominant species of the overstorey, while *Arbutus peninsularis* and *Nolina beldingii* prevail in a lower tree strata, and *Mimosa xantii* represents the dominant species of the shrub layer.

Table 1. Some community attributes of the oak and oak-pine woodlands growing in the Sierra the La Laguna, Mexico, according to their altitudinal distribution. The importance values are presented only for the 5 more important species and were estimated according to Dye & Walker (1980), and includes: H_i, individual height; N_i, number of individuals; CC_i, crown cover.

Altitude (m.a.s.l.) (Slope)	Dominant Species	Importance Value ($\Sigma H_i \cdot N_i \cdot CC_i$)	Density (ind· ha^{-1})
700	*Quercus tuberculata*	2,706.0	250.0
(North)	*Lysiloma divaricata*	535.5	1,400.0
	Dodonaea viscosa	420.9	91,700.0
	Jatropha cinerea	171.8	5,000.0
	Randia megacarpa	89.9	2,000.0
1,060	*Quercus tuberculata*	1,094.7	150.0
(West)	*Quercus devia*	623.6	250.0
	Dodonaea viscosa	201.3	2,500.0
	Erythrina flabelliformis	56.9	2,250.0
	Mimosa xantii	33.0	2,700.0
1,400	*Quercus tuberculata*	2,421.3	1,350.0
(East	*Verbesina pustulata*	822.6	4,250.0
	Dodonaea viscosa	515.4	6,850.0
	Quercus devia	110.0	50.0
	Mimosa xantii	80.6	4,800.0
1,675	*Quercus devia*	10,300.3	2,700.0
(East)	*Pinus lagunae*	4,515.9	5,150.0
	Arbutus peninsularis	1,234.9	350.0
	Nolina beldingii	368.3	1,700.0
	Mimosa xantii	239.4	8,200.0

Two other oak species occur at the oak-pine forest, *Q. rugosa* and *Q. arizonica*, but both species present a very restricted distribution within the forest.

Natural Regeneration

Natural disturbances have proved to alter the oak-pine forest because of the frequent damaging hurricanes that affect the region creating gaps in the forest canopy as a result of natural treefalls (Arriaga 1988). Gaps in this forest community are small ones (mean gap size varies between 2.5-45 m^2) mostly created by a single treefall, where three types of death prevail. Oaks generally die uprooted or else snapped off, while pines are frequently found as dead standing trees (Arriaga 1988). Gap creation produces microenvironmental changes that determine a differential establishment of species within the gap, affecting soil conditions, structural traits, diversity, and recolonization processes. In order to study the regeneration patterns of the oak-pine forest, six one-year old gaps were selected after they were opened as result of the "Kiko" hurricane, which in 1989 affected the forest.

Table 2. Structural features of the dominant species per site in gaps created by natural treefalls and in the mature forest of the oak-pine forest. The importance value includes: H_i, individual height; N_i, number of individuals; CC_i, crown cover.

Type of Disturbance and Species	Importance Value ($\Sigma H_i \cdot N_i \cdot CC_i$)	Density (ind· m^{-2})
UPT1		
Arbutus peninsularis	205.62	0.05
Quercus devia	168.69	0.04
Garrya salicifolia	56.86	0.18
Verbesina pustulata	52.74	0.80
UPT2		
Viguiera deltoidea	418.21	0.23
Calliandra peninsularis	143.91	3.08
Lepechinia hastata	56.59	0.62
Pinus lagunae	31.15	0.14
SNT1		
Pinus lagunae	367.87	0.07
Viguiera deltoidea	112.83	0.43
Quercus devia	55.50	0.05
Calliandra peninsularis	37.76	1.27
SNT2		
Quercus devia	1342.63	0.01
Viguiera deltoidea	206.08	0.21
Calliandra peninsularis	120.50	1.85
Pinus lagunae	102.39	0.02
DST1		
Quercus devia	1272.94	0.03
Viguiera deltoidea	32.23	0.31
Calliandra peninsularis	14.65	5.60
Pinus lagunae	7.83	0.37
DST2		
Pinus lagunae	194.66	0.07
Viguiera deltoidea	25.82	0.02
Lepechinia hastata	9.45	0.98
Calliandra peninsularis	3.01	0.01
MATURE FOREST		
Quercus devia	1906.52	0.02
Pinus lagunae	1896.36	0.78
Garrya salicifolia	227.97	0.11
Calliandra peninsularis	86.69	3.33

Two of the chosen gaps were produced by uprooted trees (UPT1, UPT2), two other gaps were formed by snapped off trees (SNT1, SNT2) and the last ones were created by dead standing trees (DST1, DST2). A seventh site was selected in the mature forest, where no disturbance had occurred. Within each site, all individuals were sampled and their species, height, and crown cover were recorded. In order to analyze the seed bank and to compare the seedling emergence between sites, soil samples were also obtained and germination was recorded in laboratory conditions for all sites.

Results show that the dominant species per site change according with the type of disturbance (Table 2). All of the gaps present light demanding shrubs such as *Viguiera deltoidea* and *Verbesina pustulata*, as one of the five more important species growing inside the gaps, while the more important shrub species of the mature forest are *Garrya salicifolia* and *Calliandra peninsularis*. The highest importance value for tree species was obtained in the mature forest for the oak and pine, respectively (Table 2). In other gaps, particularly in those created by snapped trees and by dead standing trees, only one of these species prevail as dominant. In either case, the oaks present a higher importance value, which might be related to their higher growth rate compare with those gaps where pines prosper as dominants.

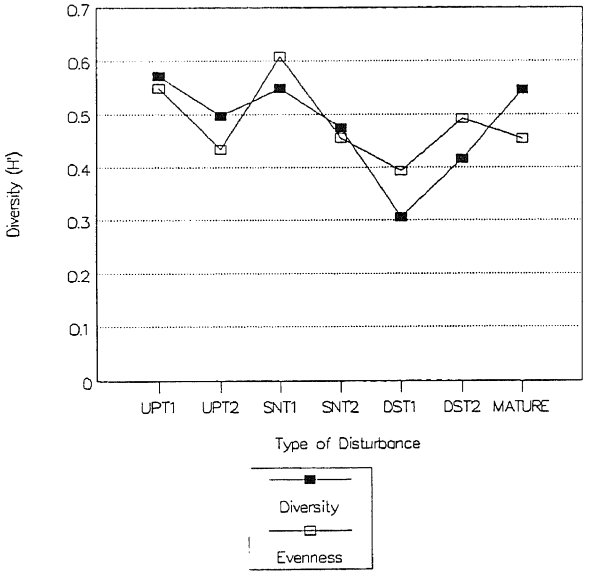

Figure 2. Species diversity and evennes in the gaps and in the mature plot of the oak-pine forest.

As expected, the simpler structural traits were obtained in the gaps created by uprooted trees, since after one year of regrowth the tallest individuals only reached 3 m; while in the other conditions (gaps created by snapped off and dead standing trees) the tallest trees were 8 m height.

Species diversity resulted significantly greater in the mature forest (Table 3), while in the gaps created by dead standing trees this is significantly smaller than in all other cases (fig. 2).

Table 3. t-Test results for differences between the diversity indices shown in fig. 2. Degrees of freedom are shown in parentheses. Significance level: *$p<0.05$, **$p<0.01$, ***$p<0.001$.

Study Site	UPT1	UPT2	SNT1	SNT2	DST1	DST2	Mature Forest
UPT1	---	2.9** (717)	0.7 (812)	3.1** (1036)	-6.7*** (478)	5.3*** (826)	0.9 (1122)
UPT2		---	2.0* (557)	-1.0 (1023)	-5.6*** (299)	-3.8*** (722)	-2.8** (3543)
SNT1			---	2.4* (8.73)	-6.1*** (457)	4.6*** (688)	0.9 (6.41)
SNT2				---	-4.3*** (455)	-2.1* (993)	-2.9** (1168)
DST1					---	-2.9** (384)	-6.9*** (326)
DST2						---	-5.8*** (858)
Mature Forest							---

This result can be explained considering that dead standing trees disintegrate gradually and therefore do not change the microenvironmental conditions so drastically as when a tree falls uprooted or snapped off.

Species diversity in gaps created by uprooted or snapped trees vary according to the disturbed area. For the same conditions (age and type of disturbance), small areas (UPT1: 71 m^2; SNT1: 160 m^2) support a signicantly higher diversity than bigger areas and they present diversity indices that do not differ significantly from the mature forest. On the contrary, large areas harbor smaller diversity indices (UPT2: 582 m^2; SNT2: 236 m^2) in relation to the same type of disturbance and to the mature forest. This outcome is probably due to a slower colonization and regeneration process occurring in large gaps because of the broader canopy openings they have, where variations in the thermic and luminic microenvironment limit the establishment or regrowth of shade-tolerant species and therefore an increment in diversity.

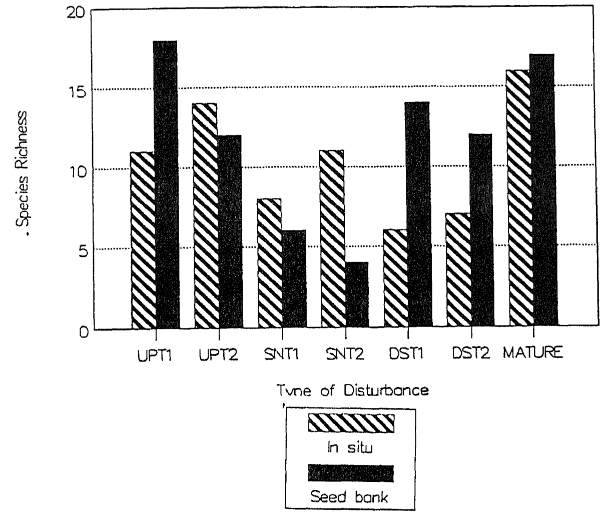

Figure 3. Species richness in the plots (*in situ*), and in their seed bank, according to the type of disturbance.

The comparison of species richness within the seed bank and in field conditions shows that in most of the study sites (UPT1, DST1, DST2, mature forest) species richness is higher in the seed bank than *in situ* (fig.3). This result is very obvious for the gaps created by dead standing trees, where the effect of disturbance is so low that species richness in the field is lesser than in their seed bank. The seed bank analysis shows that the regenerative potential of gaps created by dead standing trees is similar to the seed bank of gaps created by uprooted trees. Gaps created by uprooted trees do not present such remarkable differences in species richness between their seed bank and *in situ*, because of the significant soil removal that occurs as result of the treefall. The contrary occurs in gaps created by snapped trees where there is no soil removal and where most of the gap area is covered by the broken crown of the tree. In these gaps, the dead foliage probably intercepts the arrival of propagules that could be stored in the seed bank. Therefore, a lower species richness is found in the seed bank.

The studies concerning the natural regeneration processes where gaps are compared with the mature forest, account for some of the successional patterns and regenerative characteristics of the dominant species of the oak-pine forest. This ecological information is necessary to prescribe possible silvicultural practices in the community. Still future studies should involve a more detailed description of the population dynamics of oaks and pines in order to decide whether the woodlands are to be harvested commercially or for personal use. In this sense, we have gone a little further with the populational studies of the pinyon pine.

Pine Demography

The only pine species that grows in the Sierra de La Laguna is the endemic pinyon pine, *Pinus lagunae* (Passini 1987), which developes there as a natural stand. Four local populations were selected at the limits of the stand distribution to the north, south, east, and west, respectively. The overall area covered by these was an hectare. In each site all the individuals with a DBH > 3 cm were recorded, and their height, crown cover, DBH, and crown height were measured. Tree cores were obtained at breast height from 120 individuals of different sizes, in order to count the number of tree rings and relate them with age. Height, DBH, and crown cover frequency distributions were tested to determine whether the local populations differ among them or not. None of these distributions resulted significantly different and therefore they were considered as a single population.

Pine density resulted relatively uniform in the forest (1,734 pines per hectare), but most of the individuals present low heights, low diameters, low basal areas, and low crown covers. Pine age was determined in the laboratory by counting the tree rings and this was related to individual height according to the following simple regression model: $A = 3.62 + 5.44 H$, where: A, is individual age and H is tree height. The latter resulted in a highly significant model ($F_{1,126} = 1{,}255.46$; $p < 0.0001$), therefore pine age was estimated for the overall population based in this relationship.

A vertical life table was obtained for the pine population, however we will discuss only some of the population parameters. *Pinus lagunae* reaches a maximum height of 22 m tall and its life expectancy was estimated in 125 years. The survivorship curve obtained for this population corresponds to Pearl's type III survivorship curve, where a great decrease in seedlings and juveniles survivorship is recorded. After trees reach the age of 45 and 55 years old the survivorship remains constant (fig. 4).

The mortality curve presents a peculiar behavior (fig. 5). According to the survivorship results, a high mortality is obtained for young (6 to 8 years) and senile individuals (pines older than 95 years old); however mortality also increases in adult individuals (between 25 and 45 years old). Natural mortality occurs in early and late stages of the pine life-cycle as part of a natural process, still the reasons why adult mortality occurs are not quite

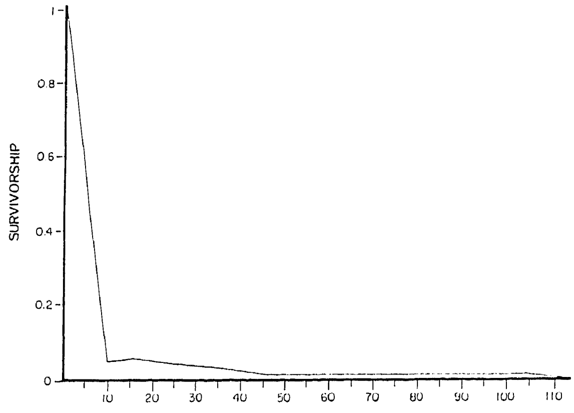

Figure 4. Survivorship curve (lx) for the *Pinus lagunae* population of the Sierra de La Laguna.

clear. According to our personal observations, mortality in adult individuals may be produced as a result of joint effects between natural fires and the severe attack of debarking larvas of lepidopterous that are present in the forest. However, future studies should considered the evaluation of insect abundance to determine if they occur in epidemic numbers.

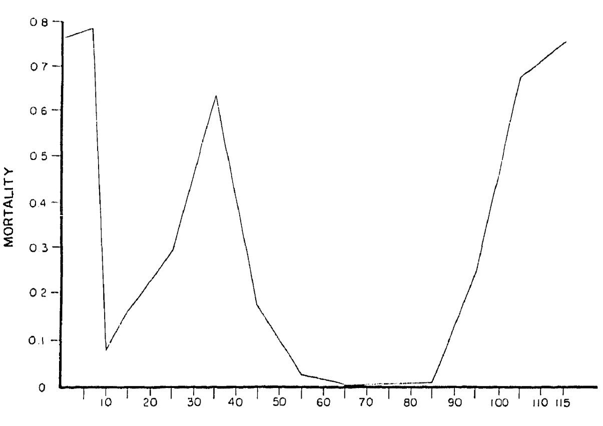

Figure 5. Mortality curve (qx) for the endemic pinyon pine population of the Sierra de La Laguna.

MANAGEMENT PERSPECTIVES

The Sierra de La Laguna and its surrounding foothills support a number of human activities such as hunting of indigenous wildlife, gathering of fuelwood, harvesting of trees for local use, and extensive livestock production; although the latter is more important in the lowlands of the Sierra. In the highlands, these activities are more restricted because of the lack of human settlements, so the influence of man has not yet affected these woodlands. From a forestry point of view, the oak and oak-pine forests have never been managed. The main reasons for the lack of exploitation is that the oak-pine forest is not suitable for wood extraction because of the small area it covers (20,000 has.), and because of the low individual sizes and volumes that the stand supports (Table 4). The maximal heights, diameters, and volumes recorded in the volumetric table only reach 16 m height, 50 cm of DBH and 12.37 m^3 of volume. Considering that the proportion of individuals bearing a commercial size is very low (Table 4), pine extraction in this forest is not justified from an economical viewpoint. From a biological standpoint, the extraction of individuals with commercial sizes would considerably decrease the regenerative capacity of the forest by diminishing its seed incorporation.

Based in the previous results, we conclude that the forest resource of the Sierra de La Laguna does not have a timber-yielding vocation because of the scarcity of commercial diameters and volumes, which are insufficient to carry out a continous, self-sustaining, and income-producing extraction of the pine resource of Baja California Sur. However, it is possible to obtain a direct production of the forest at a commercial level like tools or at a domestic level (as fuelwood, rural constructions, forest soil, etc.). Another lateral option of management for personal use could be the extraction of non-timber products such as pine nuts, that could be enhanced by the establishment of seed orchards in the forest.

Conservation of the natural resources implicitly includes forest management in order to maintain wildlife habitats and biodiversity. In this sense, the high mortality rates recorded in adult individuals suggest that deeper studies should be conducted to determine the life cycle of the lepidopterous that is affecting the pine stand, as well as studies that evaluate and quantify the magnitude and damages produced by insects in pines. These studies must be basic in order to decide whether it is necessary or not to implement healthy practices in the forest. One of these could be the elimination of dead standing trees to prevent higher degrees of infestation to preserve this endemic species.

A last consideration that should be taken into account given the socioeconomic importance of these woodlands, is the need to carry out a complete geohydrological study to determine whether some wood harvesting operations would be necessary to maintain and improve watershed protection.

Table 4. Volumetric table for *Pinus lagunae* in the oak-pine forest of the Sierra de La Laguna, B.C.S., Mexico.

DBH (cm.)	Trunk height (m) 2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0
10	0.76	0.90	0.83	0.39	----	----	----	----	----	----	----
15	----	----	0.11	0.48	0.34	0.19	----	0.27	----	----	----
20	----	----	----	0.50	1.44	1.42	1.67	----	----	----	----
25	0.10	----	0.30	----	0.49	1.72	2.66	0.74	----	----	----
30	----	----	----	----	----	0.99	2.83	1.06	2.40	----	----
35	----	----	----	----	----	----	1.94	10.59	4.91	----	----
40	----	----	0.75	----	1.26	----	----	3.89	8.92	4.90	----
45	----	----	----	----	----	----	----	----	2.86	3.18	----
50	----	----	----	----	----	4.15	2.75	12.37	7.06	8.64	----
55	----	----	----	----	----	----	3.33	----	----	----	----
60	----	----	----	----	----	----	3.96	----	----	----	6.22
65	----	----	----	----	----	----	----	----	----	6.64	7.30
70	----	----	----	----	----	----	----	----	6.93	7.30	----
75	----	----	----	----	----	----	----	----	----	----	----
80	----	----	----	----	----	----	----	----	----	----	----
85	----	----	----	----	----	----	----	9.08	----	----	----

ACKNOWLEDGEMENTS

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LITERATURE CITED

Arriaga, L. 1988. Natural disturbance and treefalls in a pine-oak forest on the Peninsula of Baja California, Mexico. Vegetatio 78: 73-79.

Arriaga, L. & Leon de la Luz, J.L. 1989. The mexican tropical deciduous forest of Baja California Sur: A floristic and structural approach. Vegetatio 84: 45-52.

Arriaga, L. & Ortega, A. 1988. La Sierra de La Laguna de Baja California. CIB-Robles Hnos. y Asoc. Publ. No. 1. México, D.F. 237 pp.

Axelrod, D.I. 1958. Evolution of the Madro Tertiary Geoflora. Botanical Reviews 24:433-509.

Brandegee, T.S. 1892. A distribution of the flora of the Cape Region of Baja California. Zoe 3: 223-231.

Dye, P.J. & Walker, B.H. 1980. Vegetation-environment relations on sodic soils of Zimbabwe. Journal of Ecology 68: 589-606.

García, E. 1981. Modificaciónes al sistema de clasificación climática de Koopen. Instituto de Geografía, U.N.A.M. México D.F. 217 pp.

Jáuregui, E. 1967. Las ondas del este y los ciclones tropicales en México. Ingeniería Hidraúlica en México 21(3): 197-208.

León de la Luz, J.L. & Domínguez-Cadena, R. 1989. Flora of the Sierra de La Laguna, Baja California Sur, Mexico. Madroño 36(2): 61-83.

León de la Luz, J.L. & Coria-Benet, R. submitted. Additions to the Flora of the Sierra de La Laguna, Baja California Sur, Mexico. Torrey Botanical Club.

Ortega, A. & Arriaga, L. 1987. Biological and Socioeconomic importance of the Sierra de La Laguna at Baja California Sur, Mexico. Proceedings of the Symposium on Biosphere Reserves. 4th World Wilderness Congress. MAB & USDA For. Serv. 207-211.

Passini, M.F. 1987. The endemic pinyon of Lower California: *Pinus lagunae* M.-F. Passini. Phytologia 63(5): 331-336.

Villa-Salas, A. 1968. La vegetación forestal en el extremo meridional de Baja California. Dirección General del Inventario Forestal. Publ. No. 10. S.A.R.H., México, 20 pp.

Distribution of Oak (Quercus spp.) in the State of Sonora, Mexico[1]

Luis Martinez Islas[2]

The State of Sonora, situated in the northeastern part of the Mexican Republic, presents numerous and varied climates that promote floristic diversity in arid and semiarid as well as more temperate climates. These more temperate climates, found in the mountainous regions in the northeast, east, and south of the State, support a great diversity of oaks (Quercus spp.). These oaks are associated primarily with conifers at the highest elevations, and form a part of the natural grasslands in the north, including the counties of Magdalena de Kino, Nogales, Imuris, Cananea, Santa Cruz, Bacoachi, Nacozari, Bacerac, Bavispe, and Huchineras.

The oaks are found in 8 of the 22 vegetation types identified by SAHR-COTECOCA and published in 1986 (see map). The most important of these vegetation types, according to the presence and number of species of quercus, are: deciduous oak woodland, located in the coldest part of the State, in the Counties of Nacori Chico, Sahuaripa, Yecora y Alamos, where 18 of the 30 species of oak are found; and the oak-pine forest, with a similar distribution and 17 species of oaks. The arbofrutescent (shrubby tree) mid-grassland is the vegetation type of greatest area, and 32 species of oak are found there.

The oaks are found over an area of about 3,585,000 hectares, dominated by the arbofrutescent vegetation type of 1,710,000 hectares and the deciduous oak woodland with 265,000 hectares.

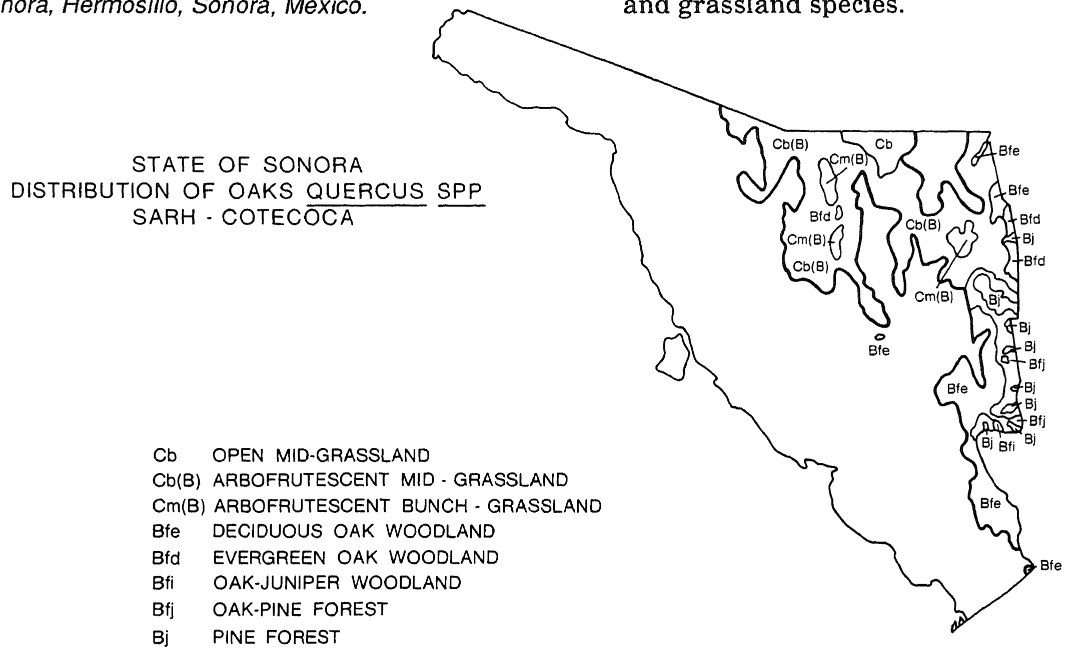
USES

At present, the oak species are little utilized, their principal uses being for the construction and maintenance of corrals, fences, and habitations by ranch owners. The potential of these species as lumber, firewood, and charcoal is not being realized. The finishing the lumber requires is a primary constraint.

The acorns of all species are consumed by cattle and wildlife, and at least one edible species, (*Quercus emoryi* is gathered for food and commercial markets.

TAXONOMY

Quercus arizonica, *Q. Chihuahuensis*, *Q. Emoryi*, and *Q. oblongifolia* have been identified from the forested areas of Sonora, as well as other woodland and grassland species.



STATE OF SONORA
DISTRIBUTION OF OAKS QUERCUS SPP
SARH - COTECOCA

Cb	OPEN MID-GRASSLAND
Cb(B)	ARBOFRUTESCENT MID - GRASSLAND
Cm(B)	ARBOFRUTESCENT BUNCH - GRASSLAND
Bfe	DECIDUOUS OAK WOODLAND
Bfd	EVERGREEN OAK WOODLAND
Bfi	OAK-JUNIPER WOODLAND
Bfj	OAK-PINE FOREST
Bj	PINE FOREST

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[1] *Paper presented at the symposium on Ecology and Mangement of Oak and Associated Woodlands: Perspectives in the Southwestern United States and Northern Mexico, April 27-30, 1992, Sierra Vista, AZ.*

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Coues White-tailed deer and the Oak Woodlands[1]

Norman S. Smith[2] and Robert G. Anthony[3]

Abstract.–The Coues white-tailed deer's distribution in Arizona is associated, in part, with the distribution of the oak woodlands. The diet of the white-tail includes many species of shrubs, trees, forbs, and grasses found within the oak woodlands and ecotonal vegetation types. The effects of disturbance in the oak woodland on white-tailed deer are unclear. Previous studies suggest that response to disturbance on the xeric periphery of the range may differ from the response in the center of the range. Studies of water use and distribution, competition with mule deer and cattle, reproduction, home range, and general ecology indicate that the white-tail may be most vulnerable to disturbance in their lower altitudinal range.

The white-tailed deer (*Odocoileus virginianus*) is widely distributed and occupies a diverse array of habitats throughout the Americas, from near-timberline in Canada to sub-equatorial South America (Baker 1984). Its ability to withstand habitat alterations, given a modicum of protection from over-harvest, has been well documented (McCabe and McCabe 1984). Indeed, the management of the white-tailed deer has been lauded as a success story. The success is, arguably, attributable to the adaptability of the species, rather than the quality of management. A list of foods eaten by white-tailed deer reveals the variety of forage suitable for America's most abundant wild ungulate. Despite the adaptability of and seeming invincibility to changing habitat, the some subspecies of white-tail have come perilously close to extinction in Mexico, South America (Halls 1984) western Oregon, and in the Florida Keys. In Arizona, the population of the Coues white-tailed deer (*O. v. couesi*) is seemingly secure but it fluctuates widely as environmental conditions, especially weather, change (Anthony 1976, Brown 1984).

The distribution of Coues white-tailed deer overlaps the distribution of the oak-woodlands in Arizona. Even though white-tailed deer occupy more mesic and more xeric habitats in Arizona, the oak woodland constitutes the heart of their range (Anon. 1977, Brown 1984, Derdeyn 1984).

In the Santa Rita Mountains of southeastern Arizona, students and faculty from the Arizona Cooperative Fish and Wildlife Research Unit have studied Coues white-tailed deer intermittently since 1970. Ted Knipe, former Game Ranger for the Arizona Game and Fish Department (AGFD) gathered information about the subspecies for years in various locations, including the Santa Rita Mountains. Many of these observations are included in a bulletin published by AGFD (Anon. 1977). From 1987 to 1990, the AGFD studied various aspects of the ecology of the white-tailed deer (Ockenfels et al. 1992).

In the heart of their range, white-tailed deer are prolific--having twins or triplets and breeding as fawns when well-nourished (Verme and Ullrey 1984). In productive populations, mortality also can be high and the population will still thrive. On the periphery of its range white-tailed deer populations fluctuate widely (Anthony 1976, Brown and Henry 1981). Fluctuations are influenced by habitat related effects on reproduction and mortality. This paper summarizes the work from previous studies on Coues white-tailed deer and how they relate to habitat, specifically, the oak-woodland. A secondary objective is to identify topics for future study.

Habitat Use by Coues White-Tailed Deer

Day (1964) investigated the forage relationships of white-tails in the Chiricahua Mountains from 1957 to 1963. He stated that white-tails inhabited all vegetation types on the mountain but the greatest densities were in the elevations from 5300 to 7000 ft and in oak-woodland, chaparral and mountain browse types. The highest elevations most used by Coues white-tailed deer were on limestone ridges and were dominated by mountain mahogany (*Cercocarpus breviflorus*), silk-tassel (*Garrya Wrightii*), alligator juniper (*Juniperus deppeana*), pinyon pine (*Pinus cembroides*), and Arizona oak (*Quercus arizonicus*). Soil on these sites was shallow. He studied lower cites located in more typical oak-woodland types than were the upper sites. Because he was studying effects of browsing, he selected heavily-used areas for plots and he described habitats mostly in feeding areas.

Anthony and Smith (1977) described habitat relationships between white-tailed deer and mule

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[1] Paper presented at the Symposium on Ecology and Management of Oak and Associated Woodlands, Sierra Vista, April 27-30, 1992

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deer (*O. hemionius crooki*) in the lower elevational range of the white-tail. In the San Cayetano Mountains, a small, isolated mountain southwest of the Santa Rita Mountains, white-tailed deer were found most often in habitat types dominated by kidneywood (*Eysenhardtia polystacha*), oak (*Quercus* spp.), sotol (*Dasylirion Wheeleri*), bear grass (*Nolina microcarpa*), grama grasses (*Bouteloua spp.*), and ocotillo (*Fouquieria splendens*) or combinations of these plants. White-tails used 18 distinct habitat types.

In the Dos Cabezas Mountains,in southeastern Arizona, Anthony and Smith (1977) found white-tails most frequently in 8 habitat types containing combinations of: oak, mountain mahogany (*Cercocarpus breviflorus*), sotol, juniper, beargrass, Grama grasses, and snowberry (*Symphoricarpos oreophilus*). Oaks dominated in 5 of the 8 most frequently used habitat types.

Ockenfels et al. (1992) studied the locations of radio-collared deer in 11 habitats in the Santa Rita Mountains of southeastern Arizona. Arizona. They found that the number of locations contributing greater than 5% of the total, in order, were in oak-mesquite, mesquite-shrub, grass-mesquite, mixed oak, oak-juniper, and other oak habitats. They reported differences in habitat use by males and females with males favoring mesquite-shrub and mixed-grass. The ratio of males:females in their sample (68 males:100 does) was weighted toward males as compared to the overall estimated ratio (20 males:100 does) in their herd composition counts during the study. Forty-nine percent of the habitats within the core areas of home ranges of does were oak- dominated and 55% of locations of both sexes were in oak-dominated habitats that constituted 38% of the total available.

Diet of White-tails in Oak Woodlands

White (1961) used the deer feeding minutes technique in the Santa Rita Mountains (4300 ft), Canelo Hills (5000 ft), and Chiricahua Mountains (8,500 ft) to estimate diets. He also estimated the relative abundance of the major species eaten. In the lower elevations, false mesquite, velvet-pod mimosa (*Mimosa dysocarpa*), and ratany (*Krameria parviflora*) were the most frequently eaten and they were highly or moderately abundant.

Day (1964) analyzed rumen contents from 120 white-tailed deer shot during November of 1958 and found that, of the identifiable plant fragments, mountain mahogany was the most frequent, and *Juniperus* sp. was the second most frequent. He also collected 30 rumen samples from deer shot at different elevations during 1957-60. At the highest elevations, white fir (*Abies concolor*), Douglas-fir (*Pseudotstuga menziesii*), and Gambel oak (*Quercus gambelii*) were the most frequent and from all elevations (5700 to 8200 ft) juniper was among the top 4 species eaten. He attributed the prevalence of the firs and juniper to reflect the lack of more desirable forage plants. He was studying an area that was overpopulated with deer.

Knipe (Anon. 1977) reported that Coues white-tailed deer ate at least 87 different species, 40 of which were summer annuals. He observed 479 deer for 2,656 deer-feeding minutes on 28 species or subspecies of trees. Oaks (*Q. emoryi*, *Q. oblongifolia*, and *Q. arizonica*) were the most common tree species eaten in the oak-grassland and mountain foothills. He noted the contribution of leaf and twig-fall from mistletoe (*Phorodendron spp.*), wild grape (*Vitus arizonicus*), and oaks to the diet. False mesquite, ratany, wild buckwheat and *Brickellia* were staple food items below the pine forests. He also remarked that mesquite was an underrated food source for white-tailed deer. Anon. (1977) stated that 610 known deer foods and 434 suspected deer foods are found in the range of the white-tailed deer south of the Mogollon Rim.

Anthony and Smith (1977) found the most frequent diet items were kidneywood, ratany, wild buckwheat, and false mockorange (*Fendlera rupicola*) in the lower elevations of San Cayetano Mountains. In higher elevations of the Dos Cabezos Mountains mountain mahogany, wild buckwheat, alligator juniper, and Gambel oak were the most frequent diet items. They also analyzed diets seasonally and found that the most common items from February to April were wild buckwheat and ratany, from May to July kidneywood dominated, from August to October kidneywood and ratany were most frequent, and from November to January kidneywood and mesquite were most frequent. These plants were not always the most abundant species available. When compared with mule deer diets, the white-tailed deer diets contained a significantly greater diversity of plants.

Ockenfels et al. (1992) found velvet-pod mimosa to be the most frequent item in the diet, as estimated by fecal analysis. They listed 23 species accounting for more than 1.0% composition.

Describing the diet without knowing what is available and how well that diet meets the needs of the animal is of limited value. We compared the estimated diets of white-tailed deer collected at the same time of the year from the same locations and 10 years apart. From 41 deer shot in 1970 and 1983 we collected fecal and rumen samples from each deer for comparison. The estimated diets differed significantly. False mesquite, alligator juniper, Emory oak, and velvet-pod mimosa were estimated to be the highest ranked diet items during 3 analyses made by Anthony and Smith (1977), Ockenfels et al. (1992) and unpublished data (Table 1).

We suspect the dissimilarities reflected differences in availability because of drought and grazing by cattle. The deer were in poorer physical condition during 1970 than they were in 1983, as indicated by body weight, kidney fat index and fecundity (Smith 1984). Diet estimates should be evaluated relative to what is being eaten, what is available, and how well that diet meets the animals needs. The diet selected from over-grazed habitats during a drought might

Table 1. Ranking of diet item frequencies in rumens and feces of Coues white-tailed deer collected in the Santa Rita Mountains, Arizona.

	1970[1]		1983[2]		1987-89[3]
Plant Species	RA[4]	FA[5]	RA	FA	FA
Calliandra eriophylla	1	1	5		7
Argemone platycerus	2	4			
Eysenhardtia poylstachya	3	3	6	5	
Garrya wrightii	4	2			
Phoradendron coryae		7			
Eriogonum wrightii	6			1	8
Juniperus deppeana	7	4			
Rhus trilobata	8	9			
Krameria parviflora	9	10	3	2	2
Prosopis juliflora	10	8	4	6	6
Psoralea tenuiflora	11	11			
Viguieria spp				3	
Artemesia ludoviciana				4	
Quercus emoryii			1		3
Chenopodium neomexicanum			2		
Mimosa dyscarpa					1
Sphaeralcea spp.					4
Notholaena parryi					9

[1] Data from Anthony and Smith (1974) average ranking of 21 rumen and fecal samples taken from the same animals after period of drought. Analyses by same people.

[2] Previously unpublished. Data are from 20 animals, paired rumen and fecal samples but analyses were by two independent labs. Non-drought conditions.

[3] Data from Okenfels et al. (1992) and analysis by same person as in fecal analysis as in 1983. Less than normal amounts of precipitation.

[4] Rumen analysis

[5] Fecal analysis

suggest that specific plants are important but, in fact, are eaten because they are the only forage available. Reproduction and survival of deer eating those plants might be poor.

The method used to estimate diets also will explain the differences. Anthony and Smith (1974) compared analyses from rumen contents and feces taken from the same animals and found that results were comparable but some items were significantly different because of differences in digestibility, easily identifiable cutin or trichrome features, or lack of cutin characteristics. Flowers, fruits, seedpods, and acorns are more easily recognized in rumen analysis than in fecal analysis. Similarities of cuticular structures of leaf surfaces also may mislead those examining the prepared slides of fecal material. The most accurate interpretations come from studies when the same researcher collects the samples, collects reference samples, prepares the samples and analyzes the samples. We believe this is true because of the researcher's familiarity with the local situation and their knowledge of what is available, the phenology of plants, and the locations of the deer. Such efforts explain the similarity of the rumen and fecal samples in the 1970 samples in contrast to the other samples. We also recognize that this approach may not always be feasible because of time and fiscal restraints.

Water Use by Coues White-tailed Deer

Maghini and Smith (1990) studied seasonal water use by Coues white-tailed deer in the Santa Rita Mountains in the summers of 1988 and 1989 and located 6 radio-collared adult does in 1988 and 7 in 1989 in an independent, non-random manner between 0500-2000 hours. Maghini and Smith (1990) located individual deer an average of 4.8 times/week and visually verified 54% of the locations. The remainder was estimated to be <100m of the plotted location. Maghini and Smith (1990) also monitored visits of radio-collared does to developed water sources with 2 scanner-receivers and chart-recorders (SRCR) continuously during the hot-dry (before summer rains) and hot-wet (after summer rains) seasons. They collected foliage from a variable number of forbs species depending on availability and 3 half-shrub, 3 shrub, and 4 tree species to estimate availability of percent moisture. Maghini and Smith (1990) also collected fecal pellets to estimate diet during the period of the study. They observed deer and cattle visits to 5 water troughs visible from a central viewing location. Times of 4-hour observation periods were randomly determined. The sampling period was from 4 June to 5 August 1989.

Maghini and Smith (1990) estimated 25 diurnal seasonal ranges and found that the ranges were largest during the hot-dry period of 1988 and smallest during the hot-wet period of 1989. Only 1 of 6 diurnal ranges contained a water source during the 1988 hot-dry season based on radio-locations and observations, but the SRCR detected 2 that used a water source outside their calculated seasonal diurnal range. In 1989 water was more available and 6 of the 7 diurnal ranges contained a water source.

Maghini and Smith (1990) found that only 8 of 933 (0.9%) deer radio-locations were at water sources because deer were at the water source for only a short time. The average time spent at or near a water source was only 36 minutes with an interval between visits of 33 hours. Furthermore, only 13 of those 36 average minutes were during daylight hours. A calculated home range might not encompass a water source when the locations were obtained only during daylight hours.

Seventy-five percent of 114 visits to the SRCR were during the hot-dry period and 25% were during the hot-wet season. During the hot-dry period, nighttime visits were more frequent ($\underline{P} < 0.001$) than would be expected based on available hours of daylight and darkness, but not during the hot-wet season ($\underline{P} = 0.10$). Deer visited the SRCR-monitored water sources during all hours of the day and night, but nighttime visits were greater than expected, especially during the hot-dry seasons. The period of greatest visitation was from 1430-2330 hours and the mode was 2100 hours. Deer did not visit troughs when cattle were present. Cattle visits declined 34% during the period of 1600-1900, whereas deer visits increased 89% during the same period.

Forage moisture contents declined through the hot-dry season, then increased after the summer rains commenced. Forbs and half-shrubs contained the most moisture in all seasons and tree foliage contained more moisture than did shrubs during the hot-dry seasons. Shrubs and trees contained more moisture in 1988 than in 1989. In the 1989 hot-dry season, plants representing the diet provided the least amount of water (40%), whereas the diets from all other seasons contained 54-59% moisture.

Based on calculations from studies by Nichol (1938), McEwen et al. (1957), and R. Henry, AGFD, unpubl. data, Maghini and Smith (1990) estimated the summer water requirements of a 32 kg doe to be 2.6 L/day. The estimated forage moisture for the driest period (hot-dry 1989) would provide 18-36% of the daily required amount and 38-77% during the wettest (hot-wet 1988). They also suggested that winter precipitation affected the number of forb species present at the beginning of the hot-dry period and affected the amount of forage moisture available in the deeper-rooted shrubs and trees as the hot and dry period continued. Their findings document the need for free-standing water, at least during the hottest and driest periods.

Complexity of Habitat and White-tailed Deer

The concept of "edge-effect" in wildlife management is nearly as old as the discipline (Leopold, 1948). Stated simply, the more interspersed the various required components of the habitat, the more game animals it can support. To a large extent the concept is still valid, with accommodation for new knowledge, (ie., some species require very large continuous blocks of undisturbed habitat, or territorial exclusion of other individuals).

In the heart of the range of white-tailed deer in North America, disturbing the climax vegetational communities often increases the complexity of their habitat relative to the availability of necessary diet items. In areas of closed canopy, such as in the northern Great Lake states, logging opened the canopy and allowed preferred diet items to increase (Blouche 1984). Throughout much of their range, white-tailed deer thrive in seral communities. Thus, as man modified habitats, white-tailed deer prospered and with protection have become pests, especially, to those whose rose bushes are eaten by deer.

On the xeric periphery of the white-tailed deer's range they may react differently to disturbed habitats, depending upon the type of disturbance. Since early arrival of white men to the range of the Coues white-tailed deer, the distribution of the subspecies has shrunk (Davis 1973, Anthony and Smith 1977, Brown and Henry 1981). Interruption of natural functioning of the oak-woodland is probably detrimental to white-tail populations. Thus, if fire is a natural component of sustaining oak-woodland complexity, interrupting the frequency of fires should be considered detrimental.

Effects of Disturbance on the Oak Woodlands

Within the range of the Arizona oak-woodlands, the principle potentially disturbing factors include fire, woodcutting, and grazing. The effect of fire on the structural complexity, species composition, richness, and synecology of the oak-woodland is not clearly understood (Baher 1991, McPherson 1992). After woodcutting, some productive stands sprout vigorously from stumps and roots with the canopy closing within 7 years (Bennett 1990, Deecken 1988). Allen (1988) stated that woodcutting, without herbicidal application, can turn open woodlands into a dense brush field. There have been no studies relating the effects of woodcutting on white-tailed deer habitat use or requirements.

Over-grazing reduces the amount of ground cover and alters the species composition of plants, particularly forbs (Anthony and Smith 1977, Brown 1984, Ffolliott 1988).

The net effect of grazing by cattle on white-tailed deer depends upon the intensity, timing, and location of the grazing; the habitat type and seral stage of the vegetation; the population level of both species; and climatic conditions. Some authors (Julander 1955, Thilenius and Hungerford 1967) concluded that forage may be used more efficiently by mule deer and white-tailed deer when the range was shared with cattle. Thilenius and Hungerford (1967) suggested that cattle-use stimulated basal sprouting of browse species. Anthony and Smith (1977) found that the Coues white-tailed deer ate a wider selection of forage species than mule deer and suggested that if habitats were simplified (e.g. by cattle grazing or drought), the white-tail were negatively affected by cattle more than were mule deer. In some circumstances, cattle may influence the areas used by deer through behavioral interactions (Ellisor 1969, Kramer 1973, and Hood and Inglis 1974, Brown 1984).

Day (1964) studied Coues white-tailed deer in the Chiricahua Mountains during a period of high populations. He concluded that cattle use of browse "was not a significant problem except at lower elevations where cattle were more abundant." The lower elevations he referred to were where desert grassland interdigitated with oak-woodland.

Ted Knipe, a long-time observer of Coues white-tails and cattle, believed that cattle use of browse species "is vastly underestimated" (Anon. 1977). He claimed that cattle depended upon browse during drought almost as much as deer did.

Brown (1984) studied habitat selection by white-tailed deer in relation to grazing intensity in the Santa Rita Mountains. He collected data from 252 sites and recorded information on 337 white-tailed deer in 146 groups and 556 cattle in 91 groups. At each site he measured grass and forb cover, by species, on 20 randomly located 0.1m^2 plots (Daubenmire 1959). He estimated use of grass and forbs by the method of Schmutz (1978). He searched for pellets and cattle feces within 0.01 ha rectangular plots. Other characteristics recorded included altitude, aspect, slope, cover sufficient to hide a fawn, distance to nearest water and estimated canopy coverage of overstory species. Brown (1984) used a step-wise multiple regression analysis with a deer use index (square root transformations of the number of deer pellets) as the dependant variable. The cattle use index and grass use were significantly ($P < 0.05$) negatively correlated with deer index. Other factors explaining the largest amount of the variation were altitude, percent cover of Gray oak, alligator juniper, velvet-pod mimosa, and Skunk-bush, (*Rhus trilobata*). The relationship of the cattle and deer indices in the *Prosopis-Fouquieria* association and on the East, South and West exposures indicated that the relationship was greatest on the drier sites.

Potential Competition Between White-tailed Deer and Mule Deer

Anthony and Smith (1977) described the Coues white-tailed deer distribution as "islands of habitat surrounded by a sea of mule deer habitat." To continue the metaphor, as tides of disturbance or climate fluctuates, the sea of mule deer habitat ebbs and flows into the white-tail's habitat. Anthony and Smith (1977) described one situation in which they believed mule deer and white-tails were competing directly (exploitation competition) and another situation in which they were competitively excluding (interference competition) each other. The diets of the two species overlapped significantly as did their selection of habitat types. They found that both species usually frequented 8 habitat types in the area where they were thought to be competing. The 8 types were *Quercus-Cercocarpus*, *Cercocarpus-Nolina*, *Juniperus-Cercocarpus*, *Quercus-Juniperus*, *Quercus-Nolina*, *Quercus-Juniperus-Cercocarpus*, *Nolina-Bouteloua*, and *Quercus-Symphoriocarpos*. The average overlap in habitat use was 75%.

In the area of competitive exclusion, overlap was less, averaging only 28%. Mule deer were found predominately in the mesquite-dominated vegetation types and the whitetails were in *Eysenhardtia-Bouteloua* habitats. Whitetails used more habitat types than did mule deer.

Ockenfels et al. (1992) speculated that in areas of sympatry the mule deer and white-tailed deer are potential competitors.

Krausman and Ables (1981) studied the Carmen mountains white-tailed deer (*O. v. carminis*) in Big Bend National Park, Texas. This subspecies frequents habitats similar to the kind selected by the Coues white-tailed deer. The Carmen Mountain subspecies was associated more with woodlands than with the lower sotol grasslands. Dense woodlands and free-standing water were necessary habitat components for white-tailed deer. Many tree and shrub species were similar to those found in the habitats of the Coues subspecies. They acknowledge that mule deer and white-tailed deer ate similar foods but thought that topography was a major separating factor.

Beasom and Krysal (1984) compared the habitats used and the diets of mule deer and white-tailed deer enclosed in a 240 ha Texas study area. They found that mule deer were more consistent in their use of habitats and food; whereas whitetails appeared more "plastic" in their diets and use of habitats. They concluded that the similarity of diets and habitats selected suggested the potential for direct competition. Their study was more on the periphery of the mule deer's range and more toward the heart of the whitetail's range.

Baker (1984) suggested that where the white-tail is slowly encroaching on mule deer it may increase the possibility of infecting the mule deer with meningeal worms to which the whitetail is adapted. Beasom and Krysl (1984) also mention encroachment and cite studies in the northern areas of contiguous distributions (Soper, 1964, Spalding 1968, and Kamps 1969). Such encroachment of whitetails into mule deer habitat is not evident on the xeric ecotone of the Coues white-tailed deer's range.

Most Vulnerable Coues White-tailed Deer Habitats

Hastings and Turner (1965) discussed the apparent upward encroachment of the desert into the oak woodland, resulting from climatic changes, fire suppression, and possibly grazing. Anthony and Smith (1977) speculated that this was the cause of mule deer being found in what was white-tailed habitat in the past. Recently, Bahre (1991) refuted the contention that climate was important and provides evidence that changes, if they are real, were caused by man's activities, specifically, fire control, grazing, and woodcutting. McPherson (1992) provides some preliminary evidence that the oaks may even be encroaching into lower elevations. Anthony (1974) and Brown (1984) presented evidence that droughts may affect white-tailed deer to a greater extent than they affect mule deer and the effects of drought would be greatest in the lower elevational range of the white-tailed deer.

The livestock industry developed many free-standing water sources, especially in the ecotone between the oak-woodland and the semi-desert grassland, which may have made this area inhabitable by white-tailed deer. Thus, cattle, mule deer, and white-tailed deer may have been forced into a position of potential competition. This ecotone also is being threatened by sub-divisions for human habitation (McClaran, et al 1992) and woodcutting will continue to be potential disturbance.

The ecology of the interface between the oak-woodland and the semi-desert grassland or desert shrub communities is poorly understood. The response of the interface to various disturbances, its importance to wildlife and human uses of it should be studied. Descriptive studies are abundant and the need now is to go beyond. Future studies should be designed experimentally and integrated with studies by plant ecologists, wildlife biologists, range managers, and urban planners.

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LITERATURE CITED

Allen, L. 1988. Range Management. Pages 75-76 *in* P. F. Ffolliott and J. D. Hasbrouck. eds. Oak woodland management: Proceedings of the workshop. School of Renewable Natural Resources, University of Arizona, Tucson, Ariz.

Anonymous. 1977. The Arizona whitetail deer. Arizona Game and Fish Dept. Special Rept. No. 6. 108pp.

Anthony, R. G. 1976. Influence of drought and diets on numbers of desert deer. J. Wildl. Manage. 40:140-144.

-------, and N. S. Smith. 1974. Comparison of rumen and fecal analysis to describe deer food habits. J. Wildl. Manage. 38:538-540.

--------, and -------. 1977. Ecological relationships between mule deer and white-tailed deer in southeastern Arizona. Ecol. Mono. 47:255-277.

Bahre, C. J. 1991. A legacy of change. Univ. of AZ Press, Tucson. 231pp

Baker, R. H. 1984. Origin, classification and distribution. Pages 1-18 *in* L. K. Halls. ed. White-tailed deer ecology and management: a Wildlife Management Institute Book. 870pp.

Beasom, S. L., and L. J. Krysal. 1984. Dietary overlap and
habitat use of a confined herd of mule and white-tailed deer. Pages 47-51 *in* P. K. Krausman and N. S. Smith. eds. Deer in the southwest: a workshop. School of Renewable Natural Resources, University of Arizona, Tucson. 131pp.

Bennett, D. A. 1990. First year effects of thinning coppice on *Quercus emoryi* in southeastern Arizona. Master's Thesis. University of Arizona, Tucson.

Blouche, R. I. 1984. White-tail populations and habitats, northern great Lakes States and Ontario forests. Pages 391-410 *in* L. K. Halls. ed. White-tailed deer ecology and management: a Wildlife Management Institute Book. 870pp.

Brown, M. T. 1984. Habitat selection by Coues white-tailed deer in relation to grazing intensity. Pages 1-6 *in* P. K. Krausman and N. S. Smith. eds. Deer in the southwest: a workshop. School of Renewable Natural Resources, University of Arizona, Tucson. 131pp.

Brown, D. E. 1984. The effects of drought on white-tailed deer recruitment in the arid southwest. Pages 7-12 *in* P. K. Krausman and N. S. Smith. eds. Deer in the southwest: a workshop. School of Renewable Natural Resources, University of Arizona, Tucson. 131pp.

Brown, D. E. and R. S. Henry. 1981. On relict occurrences of white-tailed deer within the sonoran desert in Arizona. Southwestern Naturalist 26:147-152.

Davis, G. P., Jr. 1973. Man and wildlife in Arizona: the presettlement era, 1823-1864. Master's Thesis. University of Arizona, Tucson. 251pp.

Daubenmire, R. 1959. A canopy-coverage method of vegetation analysis. Northwest Sci. 33:43-64

Day, G. I. 1964. An investigation of white-tailed deer (*Odocoileus virginianus* Cousei) forage relationships in the Chiricahua Mountains. Masters's Thesis, University of Arizona, Tucson. 101pp.

Deecken, T. 1988. Wildlife management. Pages 77-78. *in* P. F. Ffolliott and J. D. Hasbrouck. eds. Oak woodland management: Proceedings of the workshop. School of Renewable Natural Resources, University of Arizona, Tucson, Ariz.

Derdeyn, C. H. 1984 Summary of Coues white-tailed deer management on Fort Huachuca, Arizona. Pages 21-25 *in* P. K. Krausman and N. S. Smith. eds. Deer in the southwest: a workshop. School of Renewable Natural Resources, University of Arizona, Tucson. 131pp.

Ellisor, J. E. 1969. Mobility of white-tailed deer in south Texas. J. Wildl. Manage. 33:220-222.

Ffolliott, P. F. 1988. Management opportunities in the oak woodlands. Pages 83-88 *in* P. F. Ffolliott and J. D. Hasbrouck. eds. Oak woodland management: Proceedings of the workshop. School of Renewable Natural Resources, University of Arizona, Tucson, Ariz.

Halls. L. K. 1984. Research problems and needs. Pages 783-793 *in* L. K. Halls. ed. White-tailed deer ecology and management: a Wildlife Management Institute Book. 870pp.

Hastings, J. R., and R. M. Turner. 1965. The changing mile. Univ. Arizona Press, Tucson. 317pp.

Hood, R. E., and J. M. Inglis. 1974. Behavioral responses of white-tailed deer to intensive ranching operations. J. Wildl. Manage. 38:488-498.

Julander, O. 1955. Deer and cattle relationships in Utah. Forest Sci. 1:130-139.

Kamps, G. F. 1969. Whitetail and mule deer relationships in the Snowy Mountains of central Montana. M. S. Thesis. Montana State University, Bozeman. 59pp.

Kramer, A. 1973. Interspecific behavior and dispersion of two sympatric deer species. J. Wildl. Manage. 37:288-300.

Krausman, P. K. and E. D. Ables. 1981. Ecology of the Carmen Mountains white-tailed deer.U. S. Park Service. Scientific Monogr. Ser. No. 15. 114pp.

Leopold, A. S. 1948. Game Management. Charles Scribner's Sons, New York. 481pp.

Maghini, M. T. and N. S. Smith. 1990. Water use and diurnal seasonal ranges of Coues white-tailed deer. Pages 21-34 *in* P. R. Krausman and N. S. Smith. eds. Managing wildlife in the southwest. Ariz. Chap. the Wildl. Soc., Phoenix, Ariz.

McCabe, R. E. and T. R. McCabe. 1984. Of slings and arrows: An historical retrospection. Pages 19-72 *in* L. K. Halls. ed. White-tailed deer ecology and management: a Wildlife Management Institute Book. 870pp.

McClaran, M. P., L. S. Allen, and G. B. Ruyle. 1992. Livestock and grazing management in the encinal oak woodlands of Arizona. Symposium on Ecology and management of oak and associated woodlands: Perspectives in the southwestern United States and northern Mexico. April 27-30, 1992. Sierra Vista, Arizona.

McEwen, L. C., C. E. French, N. D. Magruder, R. W. Swift, and R. H. Ingram. 1957. Nutrient requirements of the white-tailed deer. Trans. North Am. and Nat. Resour. Conf. 22:119-132.

McPherson, G. R. 1992. Ecology of oak woodlands in Arizona. Symposium on Ecology and management of oak and associated woodlands: Perspectives in the southwestern United States and northern Mexico. April 27-30, 1992. Sierra Vista, Arizona.

Nichol, A. A. 1938. Experimental feeding of deer. Univ. Ariz. Agric. Exp. Sta. Tech. Bull. No. 75. 39pp.

Ockenfels, R. A., D. E. Brooks, and C. E. Lewis. 1992. General ecology of Coues white-tailed deer in the Santa Rita Mountains. Ariz. Game and Fish Dep. Tech. Report No. 6. Phoenix, Ariz. (in press)

Schmutz, E. M. 1978. Estimating range use with cattle-grazed photo guides. Univ. Arizona Coop. Ext. Serv. and Ag. Exp. Sta. Bull. No. A-73. 14pp.

Smith, N. S. 1984. Reproduction in Coues white-tailed deer relative to drought and cattle stocking rates. Pages 13-20 *in* P. K. Krausman and N. S. Smith. eds. Deer in the southwest: a workshop. School of Renewable Natural Resources, University of Arizona, Tucson. 131pp.

Soper, J. D. 1964. The mammals of Alberta. Queens Printer. Edmonton. 402p.

Spalding, D. J. 1968. The boundary deer herd. British Columbia Dep. of Recreation and Conservation Wildl. Manage. Publ. No. 2. Victoria, British Columbia. 48pp.

Thilenius, J. F., and K. E. Hungerford. 1967. Browse use by cattle and deer in northern Idaho. J. Wildl. Manage. 31:141-145.

Verme, L. J., and D. E. Ullrey. 1984. Physiology and nutrition. Pages 91-118 *in* L. K. Halls. ed. White-tailed deer ecology and management: a Wildlife Management Institute Book. 870pp.

White, R. W. 1961. An evaluation of white-tailed deer habitats and foods in southern Arizona. M. S. Thesis, Univ. of Arizona, Tucson. 60pp.

Livestock Production and Grazing Management in the Encinal Oak Woodlands of Arizona[1]

Mitchel P. McClaran, Larry S. Allen, and George B. Ruyle[2]

Abstract.–Livestock graze on nearly all of the encinal oak woodland in Arizona. The mixture of warm and cool season grasses, and some browse species provide a favorable forage resource for livestock production. Grazing systems, breeding in late summer-fall, and supplementation of phosphorus, protein, and energy can improve livestock production. Increasing residential development may reduce the profitability of livestock production by increasing land prices, property taxes, and loss of access due to more fences. Because nearly 80% of the grazing in the woodland occurs on federal land, grazing management must accommodate conflicting uses such as wildlife, rare species, oak recruitment, and recreation. This situation challenges range managers to develop strategies to accommodate conflicting uses without eliminating the economic and biologic integrity of other resources or uses.

INTRODUCTION

Approximately 85% of the 1.1 million acres of encinal oak woodland in Arizona is currently grazed by cattle. Grazing does not occur on lands administered by the National Park Service (Saguaro National Monument), and Department of Defense (Fort Huachuca); and grazing is excluded in a few areas administered by the Forest Service (Coronado National Forest). Because nearly three-fourths of the woodland is part of the Coronado National Forest unit of the U.S. Forest Service (fig. 1 and table 1), this paper will focus on the livestock production and grazing management on the Coronado National Forest.

The encinal oak woodlands in Arizona are a relatively depauperate form of the more Quercus-rich woodlands found in the Sierra Madre of northern Mexico (Brown 1982a). Only four oak species: Arizona white (*Quercus arizonica*), Emory (*Q. emoryi*), silverleaf (*Q. hypoleucoides*), and Mexican blue (*Q. oblongifolia*) are of major significance in Arizona (McPherson, this symposium) compared to over 15 species in northern Mexico (Brown 1982a). The woodland in Arizona varies from open savannas with significant grass cover at the lower elevations (4-5000 feet) to dense tree cover and little grass understory at upper elevations (6-7000 feet) (McPherson, this symposium).

Only the Tohono O'odham, Apache, and Sobaipuri Indian groups occupied southeastern Arizona when the Spanish established Jesuit settlements in the late seventeenth century (Bahre 1977; Hastings and Turner 1965). According to Officer (1987), by 1750 a mission, and several visitas and ranches were established in the desert and semi-desert grasslands at elevations lower than the oak woodland, but these were abandoned after the Pima (Tohono O'odham) Tribe revolt of 1751. In the following year, the Spanish reoccupied the area with a greater military presence and subsequent ranch establishment occurred, but formal settlement remained absent in the oak woodland. After 1821, Mexican occupancy also was limited to ranches and presidios at elevations below the oak woodland. In 1854, southern Arizona was purchased from Mexico by the United States, but significant settlement and use of the oak woodland was limited by Apache Indians that raided ranches for food and riding stock (Bahre 1991). Following the surrender of the famous Apache Chief, Geronimo in 1886, there was increased ranch and mine establishment in and near the oak woodland (Bahre 1991). The establishment of Forest Reserves between 1902-10 closed most of the oak woodland to settlement, and

Table 1. – Estimated land ownership/administration patterns of the 1.1 million acre Encinal Oak Woodland of Arizona.

Owner/Administrator	Percent
FEDERAL ADMINISTRATION	
Forest Service (Coronado National Forest)	73
Bureau of Land Management	6
National Park Service	4
Department of Defense	2
STATE ADMINISTRATION	
State Land Department	11
OTHER OWNERSHIP	
Private	3
Tohono-O'odham	1

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[1] *Paper presented at the Symposium on Ecology and Management of Oak and Associated Woodlands: Perspectives in the Southwestern United States and Northern Mexico, Sierra Vista, Arizona, April 27-30, 1992.*

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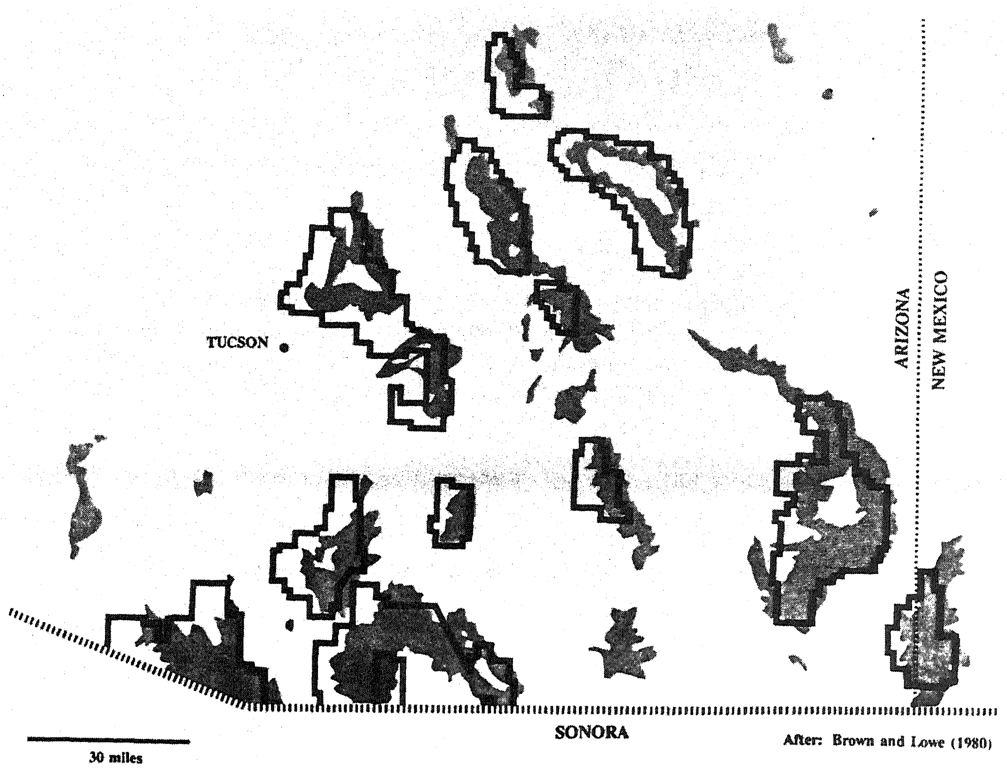


Figure 1. Location of encinal oak woodland (grey shading) and Coronado National Forest boundaries (bold solid lines) in southern Arizona. Adapted from Brown and Lowe (1980).

by 1953 these areas were consolidated as the Coronado National Forest (Allen 1989b).

HISTORY OF LIVESTOCK USE

The introduction of cattle into Arizona occurred as early as 1540 when Coronado and his contingent of Spanish explorers made their trek from Mexico to New Mexico in search of the Cities of Cibola (Christiansen 1988). However, deliberate stocking of livestock did not occur until the establishment of Spanish Jesuit settlements in the late seventeenth century (Allen 1989a). The number of livestock waxed and waned from several thousand to near 100,000 between the early 1700s and late 1800s as a result of recurring raids by the Apache Indians (Bahre 1991; Christiansen 1988; Hastings and Turner 1965). Mexican expansion after independence in 1821 re-established some abandoned ranches and developed new ranches, but by 1846 most of these were abandoned because of the persistent raids by the Apache. During this period, cattle were of Spanish origin and dominated by the Andalusian breed which is a small, rangy-looking animal that is about half the size of the current English breeds of cattle (Burcham 1981).

Livestock grazing after United States acquisition in 1854 was also limited by Apache attacks, but the industry greatly expanded following increased cavalry presence after 1870, railroad establishment in 1881, and the eventual surrender of Geronimo in 1886 (Bahre 1991; Hastings and Turner 1965). Livestock numbers skyrocketed to over 200,000 in Cochise and Pima (including present-day Santa Cruz) counties by 1890 (Bahre 1991). The animals brought to Arizona from Texas and Sonora during this period included English breeds which are significantly larger than the Andalusians (Burcham 1981). Cattle numbers plummeted due to drought in 1891-2 (Bahre 1991), increased again to a peak in 1918, and were greatly reduced by 1930 (Wagoner 1952) due to depleted forage resources and economic depression.

Because these early settlements were not located in the encinal oak woodland, and because stock-watering development in the oak woodland was uncommon, it is likely that the lower elevation semi-desert grasslands received the bulk of grazing use, and significantly less use occurred in the oak woodland.

Livestock grazing in the encinal oak woodland of Arizona increased in the mid to late 1930s with concentrated efforts to develop stock-watering facilities and fences to enhance grazing capacity and animal distribution. These efforts were financed by state and federal cost-sharing and private loan programs including the Arizona Production Credit Association, Soil Conservation Range Benefit and Range Conservation Programs administered by U.S. Department of Agriculture (Wagoner 1952). In addition, the Civilian Conservation Corps and Forest Service coordinated federal water-development and fence efforts on the Coronado National Forest (Wagoner 1952).

CURRENT LIVESTOCK PRODUCTION

Livestock production in the encinal oak woodland is characterized by low inputs of time and energy

Table 2. – Some important cattle forage species of the encinal oak woodland.

Grasses: Cool-season	
Koeleria pyramidata	junegrass
Piptochaetium fimbriatum	pinyon ricegrass
Poa fendleriana	muttongrass
Sitanion hystrix	squirreltail
Stipa eminens	southwestern stipa
Stipa neomexicana	New Mexico feathergrass
Grasses: Warm-season	
Andropogon cirratus	Texas bluestem
Andropogon scoparius	little bluestem
Aristida spp.	three awn species
Bothriochloa barbinodis	cane beardgrass
Bouteloua curtipendula	sideoats grama
B. gracilis	blue grama
B. hirsuta	hairy grama
Elyonurus barbiculmis	wooley bunchgrass
Eragrostis intermedia	Plains lovegrass
Heteropogon contortus	tanglehead
Leptochloa dubia	green sprangletop
Lycurus phleoides	wolf tail
Muhlenbergia emersleyi	bullgrass
Panicum obtusum	vine mesquite
Tridens muticus	slim tridens
Tridens pilosa	hairy tridens
Shrubs	
Calliandra eriophylla	false mesquite
Ceanothus fendleri	buckbrush
Cercocarpus montanus	mountain mahogany
Cowania mexicana	cliffrose
Eriogonum wrightii	shrubby buckwheat
Garrya wrightii	silk-tassel

because of the mild climate and high quality of the forage resource. Salt is often the only dietary supplement, bulls often are allowed to graze with the cow herd throughout the year, and water development and fences are the primary animal distribution mechanism. Nearly all ranches rely on federal or state land to sustain their cattle herds. The Forest Service administers the majority of grazing on public land in the oak woodland, and the Bureau of Land Management and Arizona State Land Department also administer some grazing.

Major cattle forage species are warm (C_4 photosynthetic pathway) and cool (C_3 photosynthetic pathway) season grasses (table 2). Warm season grass growth is most abundant from July-September when summer rains and warm temperatures occur, whereas relatively less cool season grass growth occurs in the winter and spring because winter temperatures can be too low for grass growth. Plant production (including browse and herbaceous plants) ranges from 200 to 2500 pounds per acre per year according to encinal oak woodland site descriptions developed by the Soil Conservation Service (table 3). Herbaceous production differences among sites are primarily a function of physiography and soils: the highest production sites occur on stream and alluvial fan terraces with deep, sandy loam soils.

Because cattle diets are grass-based, the nutritive quality varies among seasons (Van Soest 1982). Green grass is high in protein and phosphorus, and it is easily and completely digested. These nutrients decline rapidly after seeds are produced and as the grass dries. However, because there is a high content of cellulose in dry grass, it is a good source of energy; but low digestibility at this time can reduce total daily intake of forage.

Cattle are most likely to consume the leaves and small stems of shrubs and trees from November through January when green grass is scarce, but some amount of these plants can be found in cattle diets throughout the year. These woody species can provide protein and phosphorus that is missing from dry grass, but low digestibility can depress forage intake (Van Soets 1982). Browsing on oak appears to be insignificant, and the absence of a conspicuous browseline or highline on trees in the encinal oak woodland substantiates this insignificance. However, according to microhistological analysis of fecal material, such oak species as Emory and silverleaf can comprise as much as 25% of cattle diets during the winter (Ruyle, unpublished data).

Livestock stocking rates can be estimated from the grazing allotments on land administered by Coronado

Table 3. – Characteristics from Soil Conservation Service Woodland Site Description (Soil Conservation Service 1988).

	Mountains	Limestone Hills	Granitic Hills	Volcanic Hills	Sandy Loam Uplands
Slopes (%)	20-80	15-80	15-80	15-80	1-15
Elevation (feet)	6500-7500	5300-7200	5300-6500	5300-6500	5000-6000
Precipitation	24-27"	20-24"	20-24"	20-24"	20-24"
Canopy Cover	60%	25%	20%	20%	20%
Plant Production (pounds/acre)	200-300	400-750	450-850	700-900	1000-2500
Physiographic features	steep slopes, mountain tops, rocky outcrops	hill slopes, shallow soils, limestone outcrops	hill slopes covered with gravels, cobbles & stones	hill slopes covered with gravels, cobbles & stones	deep-sandy loam surface gravelly to very gravelly, stream terraces and fan terraces

Table 4. – Animal months, acreage of encinal oak woodland, and cattle stocking rates on land administered by Coronado National Forest in 1991.

Animal Months	210,000
Acreage of Oak Woodland	793,000
Suitable Acreage of Oak Woodland	524,000
Acres / Cow / Month	3.8
Suitable Acres / Cow / Month	2.5

National Forest. On nearly 150 allotments (roughly corresponding to 150 ranches), encinal oak woodland accounts for nearly 65% of the vegetation. The average stocking rate on these allotments is 3.8 acres / cow / month (table 4). If only suitable acreage (land that is not extremely rocky or steep) is considered, then the stocking rate is 2.5 acres / cow / month. These stocking rates correspond to the 35-55% utilization of herbaceous growth in an average year that is set by the Coronado National Forest Plan (Coronado National Forest 1988).

Livestock breeding practices have become more sophisticated in recent years. Most ranchers have shortened the calving period by adding bulls to cow herds in April and removing them in October. This pattern reduces animal handling by coordinating bull movements with spring branding and fall weaning. However, during the dry spring period, cows will often not enter esterus until the summer rains produce green forage.

Supplementation of phosphorus, protein, and energy improves cow fertility, particularly when the grass is not green. Mineral supplements, primarily phosphorus, are also made available to cattle throughout the year, but they are unnecessary when green grass is available. In all cases, the most efficient use of supplements is designed to enhance the quality of existing range vegetation rather than substituting supplementation for the lack of available forage.

Short term increases in herbaceous forage production can follow the thinning of oak canopies or tree removal, because there is less herbaceous biomass under oak canopy than in open areas (McPherson, this symposium). Because these oaks sprout prolificly after being cut or burned (Babb 1991; McPherson, this symposium), the increase of herbaceous production will be short-lived unless the trees are killed with herbicides. In situations where sprouting occurs in formerly dense woodlands, the density of sprouts can impede access and make livestock management more difficult than existed with only mature trees.

Yearlong or seasonal grazing have been the traditional practices in the encinal oak woodland of Arizona. With careful attention to animal distribution and forage utilization, these practices probably enhance individual animal performance. However, when these practices lead to poor animal distribution, they can result in over-use of preferred areas and plant species.

Conservative stocking and various schemes of rotating the presence of animals among pastures in a "grazing system" are becoming common. The Santa Rita Grazing System (Martin 1975) and a deferred-rotation system described by Schmutz (1977) are the most common systems used in the woodland. Both systems are based on the availability of three pastures (or multiples of three), with only one pasture grazed at any time and no grazing occurring during the summer and winter before re-initiating grazing in the following spring (table 5). The Santa Rita Grazing System rests (no grazing) each pasture from March to October two years out of three, with grazing occurring only in the winter between two rest periods of spring through summer (table 5). Cattle are moved twice a year: in the fall and spring. The Schmutz deferred-rotation system rests each pasture for 16 months after each 4 month grazing period (table 5). Therefore, in each year, two of the three pastures are rested either in the spring or summer growing seasons, and one pasture is rested in both growing seasons. Cattle are moved three times each year.

At least three ranches operating in the encinal oak woodland of Arizona employ the broad concept of holistic resource management (Savory 1988). On these ranches, short grazing periods are interspersed among periods of rest to prevent re-grazing of individual plants during a grazing period. Theoretically, this grazing system will allow complete recovery of grazed plants before they are re-grazed.

Increased residential development within and near the encinal oak woodland has resulted in significantly higher land values and correspondingly greater property taxes, and access problems resulting from more property boundary fences. Even though most livestock operations depend primarily on federal land grazing privileges, land prices are important

Table 5. – Grazing schedule for the Santa Rita and Schmutz's deferred-rotation grazing systems.

Santa Rita Grazing System

Grazing Year	Months	Pasture		
1	March - June	Graze	Rest	Rest
	July - October	Graze	Rest	Rest
	November - February	Rest	Graze	Rest
2	March - June	Rest	Rest	Graze
	July - October	Rest	Rest	Graze
	November - February	Graze	Rest	Rest
3	March - June	Rest	Graze	Rest
	July - October	Rest	Graze	Rest
	November - February	Rest	Rest	Graze

Schmutz's deferred-rotation system

Grazing Year	Months	Pasture		
1	March - June	Graze	Rest	Rest
	July - October	Rest	Graze	Rest
	November - February	Rest	Rest	Graze
2	March - June	Rest	Graze	Rest
	July - October	Rest	Rest	Graze
	November - February	Graze	Rest	Rest
3	March - June	Rest	Rest	Graze
	July - October	Graze	Rest	Rest
	November - February	Rest	Graze	Rest

because ownership of at least 40 acres of private grazing land is necessary to qualify for a Forest Service grazing permit. The towns of Arivaca, Sonoita, Sierra Vista, and Patagonia have experienced remarkable residential growth in traditional lot size and ranchette (5-40 acre lot) developments in the last decade. In situations of burgeoning residential development, the ability to maintain or initiate livestock grazing operations are hindered because 1) property taxes that are based on the market value of ranchland can be astoundingly high, and 2) the market value of ranchland far exceeds the income potential from livestock production (McClaran et al. 1985). Some relief from the taxation dilemma is available through differential property assessment for land under agricultural use (Arizona Revised Statutes 1989). For example, land used for livestock grazing is assessed at $14 per acre in Santa Cruz County, compared to a potential of $320 per acre as non-agricultural use land near a town. Assuming a tax rate of 14%, the tax bill for grazing land would be $1.96 per acre versus $44.80 per acre for the same land not being grazed. Although tax relief is available for existing owners, future owners will find it difficult to meet the mortgage payments from cattle grazing income when the sales price of the land reflects its potential for residential development. Of course, this situation creates the opportunity for wealth enhancement for existing ranchers when they sell property, but it is not beneficial to the future of livestock grazing.

LIVESTOCK PRODUCTION IN THE FUTURE

With the possible exception of new fencing technology, future improvements in livestock production will come from breeding season adjustments and the application of genetic research. To more closely coordinate the pattern of abundant green grass production in the summer with cow nutritive requirements for reproduction, a summer to late fall breeding season will become more common. Ranches will need to increase current efficiency and specialization beyond the current cow-calf approach. Specialization will occur from ranchers focusing on producing either replacement heifers or selling a calf crop, whereas both are produced on ranches today. Ranches will increasingly purchase replacement heifers and use new technology to increase calving efficiency and calf growth rates through genetic selection. Techniques such as artificial insemination and embryo transplanting will become much more common.

Increasing residential development will probably confine ranching to areas farther from expanding towns. Existing property tax relief programs should slow this land use conversion, but growing populations, access and neighbor problems, as well as enticing wealth enhancement from land sales will eventually lead to fewer ranches.

CURRENT GRAZING MANAGEMENT IN A MULTIPLE USE CONTEXT

The dominance of public ownership of the encinal oak woodland in Arizona requires the evaluation of livestock grazing impacts on existing plant, soil, water, and animal resources, as well as the impacts on human uses of the woodland resources.

Grazing management can impact wildlife species by altering the physical characteristics of the habitat, reducing available forage, and interfering with animal movement (Barnes et al. 1991;

Kie and Thomas 1988). In addition, the direct control of wild predators often accompanies livestock grazing operations.

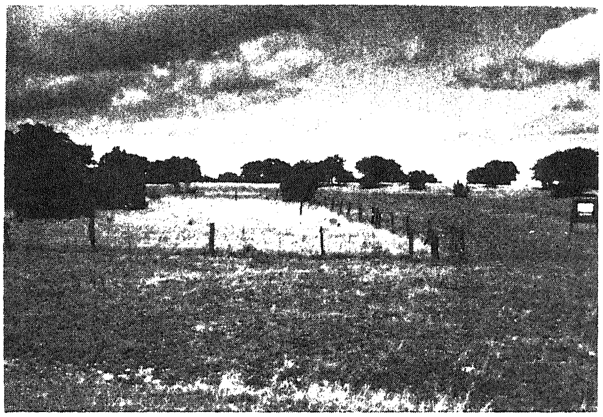
Montezuma (or Mearn's) Quail (*Cyrtonyx montezumae*) is probably the wildlife species that is most sensitive to grazing- induced changes in its oak woodland habitat. Because the quail depends on tall (≥ 6 inches) herbaceous cover to hide from predators, it is important that utilization of herbaceous biomass by livestock not exceed 45% (Brown 1982b). In addition, because seeds and tubers of forbs dominate quail diets, it may be beneficial to reduce grass growth below these levels in order to encourage forbs (Brown 1982b). Therefore, the average utilization of grass biomass should probably be between 35 and 45% for any site, but should exceed these levels in small areas to encourage forbs.

Mountain lions (*Felis concolor*) can significantly reduce calf numbers especially if calving is done where lions are concentrated. When improved livestock distribution is not effective in reducing predation, the removal of mountain lions has occurred. Because opposition to the removal of mountain lions for this reason has increased in the past ten years, all other remedies are generally exhausted before lethal control is used (Coronado National Forest 1990).

The proposed re-introduction of the Mexican Wolf (*Canis lupis balieii*) in some areas of encinal oak woodland in Arizona by the U.S. Fish and Wildlife Service may require increased efforts to manage livestock distribution and calving time to accommodate this potential predator. The wolf was extirpated from the United States and central Mexico as a result of efforts to reduce predation on livestock (Hoffmeister 1986). Although the Arizona Cattle Growers Association will not oppose the re-introduction if provisions for monetary restitution of livestock losses are made available (Arizona Cattle Growers Association 1991), it is likely that individual ranchers within the re-introduction areas will be less tolerant.

The encinal oak woodland is the site of 16 of the 54 sensitive plant species identified by Coronado National Forest, and the site of 9 of 34 plant species being considered for federal listing and protection under the Endangered Species Act (Warren 1991). Livestock grazing has been identified as posing a potential negative impact to perpetuation of the following species that are being considered for federal listing and protection: *Choisya mollis*, *Dalea tentaculoides*, *Euphorbia plummerae*, *Phaseolus* *supinus*, and *Talinum marginatum*. However, in all cases, other disturbances such as road building, mining, and trampling by campers or hikers have also been identified as posing potential negative impacts. One sensitive species, *Spiranthes delitescens*, may benefit from grazing because it prefers openings in the dense herbaceous vegetation found in cienegas within the oak woodland (McClaran and Sundt *in press*).

The influence of grazing management on oak seedling recruitment is not fully understood (McPherson, this symposium). However, three lines of evidence suggest that current grazing management probably does not significantly reduce oak recruitment: 1) absence of a browseline on nearly all oak trees, 2) low representation of oak in cattle diets, and 3) lack of obvious differences in oak recruitment between ungrazed exclosures and adjacent grazed areas (fig. 2). The lack of obvious negative grazing impacts is strikingly different from the situation in the California Oak Woodland (McClaran and Bartolome 1989, 1990), and may reflect the greater abundance of green herbaceous material during all times of the year in Arizona.



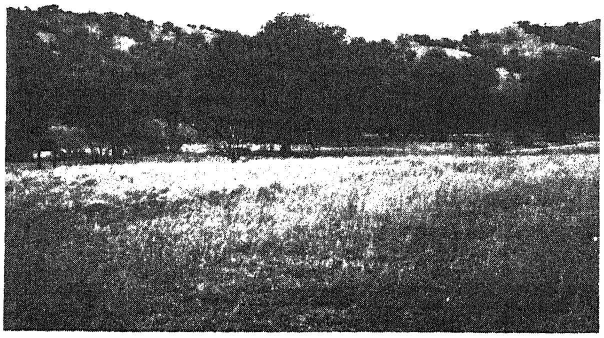


Figure 2. Examples of the lack of oak recruitment in ungrazed livestock exclosures and adjacent grazed areas. Vaughan (top photo) exclosure (Township 21S Range 18E Section 31) was established in 1925 and is 5200 feet in elevation. Hog Canyon (bottom photo) exclosure (Township 20S Range 16E Section 21) was established in 1940 and is at 4700 feet elevation (Turner et al. 1980). Both photographs were taken in March 1992.

Recreational use by hunters, birdwatchers, and campers is not always compatible with livestock grazing. Deer and quail hunting seasons bring thousands of people to the backroads in the encinal oak woodland every year. Birdwatching enthusiasts flock to observe species that appear in the United States only in these woodlands. Finally, campers find the cool summer temperatures a welcome respite from the lower elevation cities of Arizona. These are legal and legitimate uses of the federal land administered by the Forest Service (Coronado National Forest) and Bureau of Land Management, and they provide significant income to small towns within and near the woodland (United States Fish and Wildlife Service 1989). To reduce and prevent use conflicts, grazing management should direct animal distribution away from popular areas during peak use periods.

Range managers have become increasingly aware of the variety of uses occurring on public rangelands, and of their responsibility to manage the impacts of all rangeland uses, not only livestock grazing. In this context, all uses including livestock grazing must be coordinated. Some ranchers may perceive as blasphemous any requests by the Coronado National Forest to alter their grazing practices in order to accommodate other uses. Similarly, other users may suspect preferential treatment for grazing when asked to accommodate livestock use. There are no easy answers to these use conflicts. However, it does appear that ranchers who can continue to generate a profit from their livestock operation after accommodating other uses are more likely to fulfill those obligations in good faith than ranchers whose accommodations lead to an absence of profit.

GRAZING MANAGEMENT AND MULTIPLE USE IN THE FUTURE

Grazing management will increasingly accommodate other resources and uses in the federally-owned portions of the encinal oak woodland of Arizona. The challenge to range managers, livestock producers, and other users will be to select grazing management strategies that minimize impacts to the physical and biological resources and other users, while providing for a profit from grazing. Application of the Coordinated Resource Management Planning process (Anderson 1990; Anderson and Baum 1988), in which all interested parties are involved in the development of Allotment Management Plans and resource monitoring efforts, can facilitate the accommodation of conflicting uses without removing the profit from the livestock operation.

Wildlife conservation, rare and sensitive species protection, and recreational use are range management goals that will continue to be important. Because the livestock industry has been perceived as antagonistic to these goals, it will become increasingly important for them to initiate, promote, and advertise grazing management that accommodates other uses. The livestock producer associations such as the Arizona Cattle Growers Association, Graham-Cochise Cattle Growers Association, and Southern Arizona Livestock Protection Association can play an important role in this process. The Arizona Cattle Growers accommodating stance on the re-introduction of the Mexican wolf is an example of this type of leadership. Finally, these associations have begun to initiate a process of self-regulation in which ranchers that are not conforming to acceptable range management practices are identified and chastised. If this move toward self-regulation continues, then these associations will go far in reversing the antagonist image and gain considerable respect from other rangeland users.

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LITERATURE CITED

Allen, L.S. 1989a. Roots of the Arizona livestock industry. Rangelands 11:9-13.

Allen, L.S. 1989b. Livestock and the Coronado National Forest. Rangelands 11:14-20.

Anderson, E.W. 1990. Tips on initiating a coordinated plan. Rangelands 12:262-263.

Anderson, E.W. and R.C. Baum. 1988. How to do coordinated resource management planning. Journal of Soil and Water Conservation 43:216-220.

Arizona Cattle Growers Association. 1991. Wolf resolution amended. Market Report and Newsletter 72(36):1,4.

Arizona Revised Statutes. 1989. Property used for agricultural purposes; criteria; applications; additional tax; definition. 42 ARS 167.

Babb, G.D. 1991. Sprouting response of *Quercus arizonica* and *Quercus emoryi* following fire. M.S. Thesis, University of Arizona. 77 pp.

Bahre, C.J. 1977. Land-use history of the Research Ranch, Elgin, Arizona. Journal of the Arizona Academy of Sciences 12 (supplement 2):1-32.

Bahre, C.J. 1991. A Legacy of Change: Historic Human Impact on Vegetation in the Arizona Borderlands. University of Arizona Press. 231 pp.

Barnes, T.G., R.K. Heitschmidt, and L.W. Varner. 1991. Wildlife. In, R.K. Heitschmidt and J.W. Stuth (eds.). Grazing Management: An Ecological Perspective. Timber Press. pp. 179-189.

Brown, D.E. 1982a. Madrean oak woodland. In, D.E. Brown (ed.) Biotic Communities of the American Southwest - United States and Mexico. Desert Plants 4:59-65.

Brown, D.E. and C.H. Lowe. 1980. Biotic communities of the southwest. U.S.D.A. For. Serv. General Technical Report RM-78.

Brown, R.L. 1982b. Effects of livestock grazing on Mearn's quail in southeastern Arizona. Journal of Range Management 35:727-732.

Burcham, L.T. 1981. California Range Land. Center for Archeological Research at Davis Publication Number 7, University of California, Davis. 256 pp.

Christiansen, L.D. 1988. The extinction of wild cattle in southern Arizona. Journal of Arizona History 29:89-100.

Coronado National Forest. 1988. Coronado National Forest Plan. U.S.D.A. For. Serv. Southwest Region. 130 pp.

Coronado National Forest. 1990. Animal Damage Management Plan. U.S.D.A. For. Serv. Southwest Region.

Hastings, J.R. and R.M. Turner. 1965. The Changing Mile: An Ecological Study of Vegetation Change in the Lower Mile of an Arid and Semiarid Region. University of Arizona Press. 317 pp.

Hoffmeister, D.F. 1986. Mammals of Arizona. University of Arizona Press. 602 pp.

Kie, J.G. and J.W. Thomas. 1988. Rangeland vegetation as wildlife habitat. In, P.T. Tueller (ed.). Vegetation Science Applications for Rangeland Analysis and Management. Kluwer Academic Publishers. pp. 585-605.

Martin, S.C. 1975. Ecology and management of southwestern semidesert grass-shrub ranges: the status of our knowledge. U.S.D.A. For. Serv. Research Paper RM-156. 39 pp.

McClaran, M.P. and J.W. Bartolome. 1990. Comparison of actual and predicted blue oak age structures. Journal of Range Management 43:61-63.

McClaran, M.P. and J.W. Bartolome. 1989. Fire related recruitment in stagnant *Quercus douglasii* populations. Canadian Journal of Forest Research 19:580-585.

McClaran, M.P., J. Romm, and J.W. Bartolome. 1985. Differential farmland assessment and land use planning relationships in Tulare County, California. Journal of Soil and Water Conservation 40:252-255.

McClaran, M.P. and P.C. Sundt. in press. Population dynamics of the rare orchid, *Spiranthes delitescens*. The Southwestern Naturalist.

McPherson, G.R. *this symposium*. Ecology of oak woodlands in Arizona. in P.F. Ffolliott (tech. coord.) Symposium on Ecology and Management of Oak and Associated Woodlands: Perspectives in the Southwestern United States and Northern Mexico. U.S.D.A. Forest Service General Technical Report RM- ???.

Officer, J.E. 1987. Hispanic Arizona, 1536-1856. University of Arizona Press. 462 pp.

Savory, A. 1988. Holistic Resource Management. Island Press. 563 pp.

Schmutz, E.M. 1977. A deferred-rotation grazing system for southwestern ranges. University of Arizona Cooperative Extension Publication Number Q179.

Soil Conservation Service. 1988. Range site guide for major land resource area 41-1. Soil Conservation Service Technical Guide.

Turner, R.M., L.H. Applegate, P.M. Bergthold, S. Gallizioli, and S.C. Martin. 1980. Arizona range reference areas. U.S.D.A. Forest Service General Technical Report RM-79. 34 pp.

Van Soest, P.J. 1982. Nutritional Ecology of the Ruminant. O & B Books, Inc. 374 pp.

Wagoner, J.J. 1952. History of the Cattle Industry in Southern Arizona, 1540-1940. University of Arizona Social Science Bulletin 20, University Arizona Press. 132 pp.

Warren, P. (ed.). 1991. Sensitive plant species of the Coronado National Forest. Arizona Game and Fish Department, Heritage Data Management Program, Phoenix, Arizona.

United States Fish and Wildlife Service. 1989. 1985 National Survey of Fishing, Hunting, and Wildlife Associated Recreation, Arizona.

Use of Oaks by Neotropical Migratory Birds in the Southwest[1]

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Abstract.–We recorded 98 species of neotropical migratory birds in vegetation types containing oaks in southeastern Arizona and southern California. Neotropical migrants used these areas as breeding and migration habitat. Little similarity was found in the neotropical bird assemblages of California and Arizona. Within Arizona, bird assemblages were most similar between mixed-conifer forest and pine-oak woodland. Use of oaks for foraging ranged from 17.4% to 73.7% of the foraging attempts for the nine species studied. These birds each used species of oaks in unique proportions.

INTRODUCTION

Oaks (*Quercus* spp.) provide resources to meet life requisites of numerous resident and migratory birds. Specific needs provided by oaks and associated flora include food and cover, and nest, roost and perch sites. Some birds rely on oaks more than others, and some species exhibit preferences for certain types or structures of oaks. Lamb (1989) recognized 15 species of oaks in Arizona and New Mexico. More than 17 species of oaks occur in California (Block et al. 1990). This diversity of oaks is enhanced by the propensity of oaks to hybridize when ranges overlap. Oaks occur in a variety of vegetation types ranging from monotypic woodlands to understory components in conifer-dominated forests. They inhabit environments that range from xeric to mesic.

The importance of oaks for birds within a vegetation type can differ (Marshall 1957, Balda 1967), and the importance of oaks to birds can shift seasonally or yearly (Block 1989, 1990, 1991; Block and Morrison 1991). Marshall (1957) found higher densities of breeding birds in pine-oak and encinal woodlands than he found in the nine other vegetation types he surveyed in southeastern Arizona. Balda (1967) noted that 48% of the birds found in woodland types of the Chiricahua Mountains were not found in any other types.

Neotropical migratory birds typically breed in temperate environments of North America and winter in tropical environments of Central and South America. On their breeding grounds and along migration routes these birds use a variety of habitats, many containing oaks, to supply resources required for reproduction and survival. The migratory habit sets these birds apart from many resident species because they require a variety of resources to meet a variety of conditions. For example, Hutto (1985) observed that migrating passerines in the Chiricahuas used different habitats from the ones used on the breeding grounds. Hutto (1985) thought that migratory birds were restricted to use of breeding habitat by nest-site requirements and hence could use a wider range of habitats during migration. Hence, oaks probably provide critical resources for both breeding and migrating birds that use them.

Population numbers of many species of neotropical migratory birds are believed to be declining (Finch 1991). Although the factors causing these population declines are unknown, habitat loss and fragmentation, both on breeding and wintering grounds, are assumed to be among the most important factors. Thus, information that details habitat associations and patterns of habitat use by these birds is critical to determining the effects of habitat change on their populations.

The purpose of this paper is to describe the types, general distributions, and macrohabitat associations of neotropical migratory birds during breeding and migration in southwestern forests and woodlands containing oaks. We will draw upon two studies – a completed project in southern California, and an ongoing study in the mountains of southeastern Arizona – to examine macrohabitat associations and use of oaks by foraging birds.

STUDY AREAS

The southern California study area was located on Tejon Ranch in the Tehachapi Mountains of Kern County. The ranch is a private holding encompassing about 100,000 ha, half of which is oak woodland. We confined our study area to about 2,500 ha of this oak woodland. The climate at Tejon Ranch is Mediterranean with hot, dry summers and cool, wet winters. Elevation ranges from 1100 to 1700 m. Major tree species include blue oak (*Quercus douglasii*), valley oak (*Q. lobata*), California black oak (*Q. kelloggii*), interior live oak (*Q. wislizenii*), canyon live oak (*Q. chrysolepis*), Brewer's oak (*Q. garryana* var. *breweri*), and California buckeye (*Aesculus californica*). These trees generally occur in stands of single species with mixes of stands along narrow ecotones. Exceptions to this pattern are mixed stands of buckeye, canyon live, interior live, California black, and Brewer's oaks that occur on the higher-elevational, north-facing slopes.

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The Arizona study areas were located on five mountain ranges in southeastern Arizona: the Chiricahua, Pinaleno, Santa Rita, Santa Catalina, and Huachuca mountains. Vegetation types of these mountains that we sampled include oak, oak-juniper and pine-oak woodlands, and mixed-conifer forests. Primary species of oaks are Emory oak (*Q. emoryi*), Arizona white oak (*Q. arizonae*), silverleaf oak (*Q. hypoleucoides*), netleaf oak (*Q. reticulata*), and Gambel oak (*Q. gambelii*). Oaks occur in monotypic stands often of Emory oak, or mixed stands of Emory and Arizona white oaks, alligator juniper (*Juniperus deppeanna*), and Mexican pinyon (*Pinus cembroides*), or in stands of pine-oak including Arizona white, silverleaf, netleaf, or Emory oaks mixed with Chihuahua (*Pinus leiophylla*), Apache (*P. engelmannii*), ponderosa (*P. ponderosa*), or mexican white (*P. flexilis* var. *reflecta*) pines. Gambel oak is found as an understory component of mixed-conifer stands, which also include Douglas-fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), and various pine species.

METHODS

Field Methods

Tejon Ranch

A point-count method (Reynolds et al. 1980, Verner 1985) was used to sample bird populations during the 1986, 1987, and 1988 breeding seasons (March through June). Observers recorded all birds detected at fixed points during a 5-min period. One hundred points were established using a systematic-random-sampling procedure (Cochran 1977). Ten points were systematically arrayed along each of 10 transects. Points were from 300 to 400 m apart to ensure sampling independence among points (i.e., not counting the same bird at adjacent points).

Birds were counted at each point 3 times during the season to account for temporal variations in bird detectabilities.

Southeastern Arizona Mountains

We placed from 24 to 72 counting stations on each mountain range. Stations were arrayed at 300-m intervals on transects along random bearings. Two to six transects were placed on each mountain range. We used the same methods to record birds as described above for Tejon Ranch. Points were assigned to vegetation type – oak, oak-juniper, pine-oak, mixed conifer – based on the dominant trees present.

We also recorded foraging observations for a subset of the birds by noting the species, height, diameter, and crown width of the tree where the birds were observed foraging. We also recorded data pertaining to location of the bird in the tree, perch and foraging substrates, and foraging maneuver. An observer watched a bird for 20 seconds but recorded information only from the second 10 seconds to avoid sampling only conspicuous behaviors of the bird. Species for which we collected foraging data included the elegant trogon (*Trogon elegans*), hermit thrush (*Catharus guttatus*), hepatic tanager (*Piranga flava*), black-headed grosbeak (*Pheucticus melanocephalus*), Virginia's warbler (*Vermivora virginiae*), Lucy's warbler (*V. luciae*), red-faced warbler (*Cardellina rubrifrons*), painted redstart (*Myioborus picta*), yellow-rumped warbler (*Dendroica coronata*), black-throated gray warbler (*D. nigrescens*), Grace's warbler (*D. graciae*), and olive warbler (*Peucedramus taeniatus*).

Data Analysis

We stratified counting stations in southeastern Arizona according to major cover types: mixed-conifer forest, pine-oak woodland, or oak woodland. We pooled data from all Arizona mountain ranges to ensure adequate sample sizes for general comparisons. Species were regarded as neotropical migratory birds if they appeared on the official list of migratory birds prepared by the Neotropical Migratory Bird Conservation Program (Gauthreaux 1991), although this list has been the subject of debate (SWCA 1991). We performed pairwise comparisons of the neotropical migratory birds found in the three Arizona cover types and the neotropical migrants from the Tehachapi Mountains using Jaccard's (1912) similarity coefficient to measure the proportion of the total species pool common to both areas.

We calculated Spearman rank-order correlation coefficients (Marascuilo and McSweeny 1977) on detection frequencies to compare rankings of species abundances among the three major cover types of southeastern Arizona. To evaluate the importance of oaks to bird foraging, we calculated the percentage of each species that used oak during foraging.

RESULTS

Observers recorded 114 species, including 73 neotropical migratory birds, during counts in Arizona. The largest number of species recorded was in pine-oak woodland and the fewest number was in oak woodland (table 1). California's Tehachapi Mountains contained the fewest number of recorded resident birds but had the largest number of neotropical migrant species (table 1). Similarity of neotropical

Table 1. – Numbers of resident and neotropical migrant bird species found in mountains of southeastern Arizona during the 1991 breeding season and the Tehachapi Mountains, California, during the 1986, 1987, and 1988 breeding seasons.

	Arizona mountains			
	Mixed-conifer (n=72)[a]	Pine-oak (n=128)	Oak (n=48)	Tehachapi Mountains (n=100)
Resident	33	43	31	24
Neotropical migrant	44	54	41	63

[a] Number of counting stations.

Table 2. – Jaccard (1912) coefficients comparing neotropical migrant birds found in mixed-conifer forest, pine-oak woodland, and oak woodland during the 1991 breeding season in the southeastern Arizona mountains and in the Tehachapi Mountains, California, during 1986, 1987, and 1988 breeding seasons.

	Mixed-conifer	Pine-oak	Oak
Tehachapi Mountains	0.31	0.28	0.26
Mixed conifer	-	0.66	0.40
Pine oak	–	–	0.45

migratory bird assemblages between study sites ranged from 0.26 to 0.66 (table 2). Little similarity was found between neotropical migratory bird assemblages in California and those in Arizona (table 2). The lack of similarity between the Tehachapi and Arizona groups of neotropical birds was attributable to species that were detected only in the Tehachapis or only in southeastern Arizona (table 3). In Arizona, pine-oak woodland and mixed-conifer forests were most similar (table 2). Ranking of species abundances were significantly correlated ($r_s = 0.74$, $P < 0.001$) between pine-oak and mixed-conifer, but not between pine-oak and oak ($r_s = 0.27$, $P > 0.05$) or mixed-conifer and oak ($r_s = 0.03$, $P > 0.5$). Species observed only in Arizona pine-oak woodlands included zone-tailed hawk, gray hawk, flammulated owl, elegant trogon, blue-throated hummingbird, and magnificent hummingbird (table 3). The northern mockingbird, loggerhead shrike, Lucy's warbler, black-chinned sparrow, and green-tailed towhee were observed only in the oak woodlands that we surveyed in Arizona. No species were unique to mixed-conifer forests (table 3).

Observers recorded 521 foraging observations of neotropical migratory birds in the Arizona mountains. Small sample sizes (from 1 to 5) for the elegant trogon, orange-crowned warbler, olive warbler, and Lucy's warbler precluded analysis for these species. Other species used oaks for foraging from 17.4% (hermit thrush) to 73.7% (black-throated gray warbler) of their foraging attempts (table 4). Silverleaf oak was used most frequently by the painted redstart, red-faced warbler, Grace's warbler, and Virginia warbler (table 4). The black-throated gray warbler used silverleaf and Arizona white oaks with comparable frequencies (table 4). The black-headed grosbeak and hermit thrush used Arizona white oak with greater frequency than other oaks (table 4). Yellow-rumped warbler used silverleaf, Emory, and Gambel oaks with comparable frequencies (table 4).

DISCUSSION

We found 98 species of neotropical migratory birds using vegetation types containing oaks in southeastern Arizona and California. Most of these birds used these vegetation types for breeding; others such as hermit and Townsend's warblers used them as habitat during migration to and from their breeding grounds or during other parts of the year. For example, of the 63 species in the Tehachapi Mountains that we identified as neotropical migrants (based on Gauthreaux [1991]), 32 species were migrating, wintering, or incidental species that did not breed there (Block 1989). Far fewer of the neotropical birds found in our southeastern Arizona study areas were nonbreeding birds. Simply because some species did not breed in our study areas does not negate the importance of those habitats to the birds. Likely, the resources that these birds derived from the oaks were important to their survival and ultimate fitness.

We found little similarity in the species or relative abundances of birds found in oak woodlands compared with those found in pine-oak woodland or mixed-conifer forests. This apparent difference suggests that oak woodlands provide resources for unique assemblages of birds. Many of these birds have specific needs (such as nest sites as suggested by Hutto [1985]) or a combination of biological needs that are met by environmental conditions unique to oak woodlands. Thus, a particular species may be able to derive needed resources from oak woodland, but not from pine-oak woodland or mixed-conifer forest.

Many of the observed differences in the avifaunas of California and Arizona were attributed biogeographic differences. For example, the geographic distributions of many Arizonan birds do not extend to California, and vice versa (table 3). Further, some species occur in both regions and may breed in one region but only migrate through the other. Thus, range differences of birds and the great diversity of vegetation types containing oaks acted synergistically to provide suitable habitat for numerous breeding and migrating neotropical birds. Given the diversity of habitats and birds that use them, different management approaches probably will be needed for different situations.

We found that birds used oaks extensively for foraging. Different species of oaks were used in different proportions by each bird species we studied. Even birds such as Grace's warbler, red-faced warbler, and painted redstart that are closely tied to conifer-dominated habitats used oaks extensively for

Table 3. – Number of counting stations where neotropical migrant birds were detected in 3 major cover types (mixed-conifer forest, pine-oak woodland, and oak woodland) in southern Arizona mountains and oak woodlands of the Tehachapi Mountains, California. The lists for Arizona are based on the results of sampling 248 counting stations during 1991 breeding season; the Tehachapi Mountain list is derived from counts of 100 stations during 1986, 1987, and 1988 breeding seasons.

Species	Arizona mountains			Tehachapi Mountains (*n*=100)
	Mixed-conifer (*n*=72)[a]	Pine-oak (*n*=128)	Oak (*n*=48)	
Killdeer (*Charadrius vociferus*)	0	0	0	1
Sharp-shinned hawk (*Accipiter striatus*)	0	0	0	3
Cooper's hawk (*A. cooperii*)	0	0	0	4
Red-tailed hawk (*Buteo jamaicenses*)	2	1	2	30
Zone-tailed hawk[b] (*B. albonotatus*)	0	1	0	0
Gray hawk[b] (*B. nitidus*)	0	1	1	0
Golden eagle (*Aquila chrysaetos*)	0	0	0	4
Turkey vulture (*Cathartes aura*)	3	6	4	0
American kestrel (*Falco sparverius*)	0	0	1	3
Long-eared owl (*Asio otus*)	0	0	0	1
Flammulated owl (*Otus flammeolus*)	0	1	0	0
Elegant trogon[b] (*Trogon elegans*)	0	21	0	0
Mourning dove (*Zenaida macroura*)	3	11	37	100
White-winged dove (*Z. asiatica*)	0	0	2	10
Band-tailed pigeon (*Columba fasciata*)	15	14	0	1
Anna's hummingbird (*Calypte anna*)	0	0	0	35
Broad-tailed hummingbird (*Selasphorus platycercus*)	36	18	7	0
Rufous hummingbird (*S. rufus*)	1	1	0	0
Blue-throated hummingbird[b] (*Lampornis clemenciae*)	0	2	0	0
Magnificent hummingbird[b] (*Eugenes fulgens*)	0	1	0	0
Lewis woodpecker (*Melanerpes lewis*)	0	0	0	1
Red-breasted sapsucker (*Sphyrapicus ruber*)	0	0	0	2
Red-naped sapsucker (*S. nuchalis*)	1	0	0	0
Western kingbird (*Tyrannus verticalis*)	0	0	3	22
Cassin's kingbird (*T. vociferans*)	0	14	18	0
Dusky-capped flycatcher[b] (*Myiarchus tuberculifer*)	14	67	7	0
Ash-throated flycatcher (*M. cinerascens*)	1	29	24	100
Sulphur-bellied flycatcher[b] (*Myiodynastes luteiventris*)	5	12	0	0
Western wood-pewee (*Contopus sordidulus*)	1	9	2	42
Greater pewee[b] (*C. perfinax*)	34	37	0	0
Olive-sided flycatcher (*C. borealis*)	1	0	0	1
Hammond's flycatcher (*Empidonax hammondii*)	0	0	0	4
Dusky flycatcher (*E. oberholseri*)	1	4	1	3
Gray flycatcher (*E. wrightii*)	0	0	2	2
Pacific-slope flycatcher[c] (*E. difficilis*)	0	0	0	1
Cordilleran flycatcher[b] (*E. occidentalis*)	27	9	0	0
Northern beardless-tyrannulet[b] (*Camptostoma imberbe*)	0	1	0	0
White-throated swift (*Aeronautes saxatalis*)	1	5	1	0
Tree swallow (*Tachycineta bicolor*)	0	0	0	1
Violet-green swallow (*T. thalassina*)	9	1	0	95
Purple martin (*Progne subis*)	0	0	0	1
Barn swallow (*Hirundo rustica*)	0	0	0	1
House wren (*Troglodytes aedon*)	21	14	2	100
Rock wren (*Salpinctes obsoletus*)	0	3	8	0
Ruby-crowned kinglet (*Regulus calendula*)	0	2	2	6
Blue-gray gnatcatcher (*Polioptila caerulea*)	5	3	3	23
Northern mockingbird (*Mimus polyglottus*)	0	0	9	0
American robin (*Turdus migatorius*)	43	33	0	53
Townsend's solitaire (*Myadestes townsendi*)	7	0	0	1
Hermit thrush (*Catharus guttatus*)	56	40	1	5
Western bluebird (*Sialia mexicana*)	1	2	3	81
Loggerhead shrike (*Lanius ludovicianus*)	0	0	1	0
Cedar waxwing (*Bombycilla cedrorum*)	0	0	0	2
Phainopepla (*Phainopepla nitens*)	0	0	2	1
Solitary vireo (*Vireo solitarius*)	48	56	4	10
Bell's vireo (*V. bellii*)	1	5	2	0
Warbling vireo (*V. gilvus*)	21	2	1	23
Yellow-rumped warbler (*Dendroica coronata*)	37	29	0	76
Townsend's warbler (*D. townsendi*)	0	2	0	17
Hermit warbler (*D. occidentalis*)	1	1	0	26
Black-throated gray warbler (*D. nigrescens*)	32	88	28	32
Painted redstart[b] (*Myioborus picta*)	48	64	1	0
Red-faced warbler[b] (*Cardellina rubrifrons*)	56	57	0	0
Olive warbler[b] (*Peucedramus taeniatus*)	9	7	0	0
Grace's warbler[b] (*Dendroica graciae*)	50	54	0	0
Virginia's warbler[b] (*Vermivora virginiae*)	8	16	0	0
Lucy's warbler (*V. luciae*)	0	0	3	0
Nashville warbler (*V. ruficapilla*)	0	0	0	14
MacGillivray's warbler (*Oporornis tolmiei*)	0	0	0	2
Yellow warbler (*Dendroica petechia*)	0	0	0	1
Orange-crowned warbler (*Vermivora celata*)	4	2	0	20
Wilson's warbler (*Wilsonia pusilla*)	1	0	0	37
Brewer's blackbird (*Euphagus cyanocephalus*)	0	0	0	15
Red-winged blackbird (*Agelaius phoeniceus*)	0	0	0	4
Western meadowlark (*Sturnella neglecta*)	0	0	0	24
Brown-headed cowbird (*Molothrus ater*)	1	4	7	19

Table 3. – continued from page 4

Species	Arizona mountains Mixed-conifer (*n*=72)[a]	 Pine-oak (*n*=128)	 Oak (*n*=48)	Tehachapi Mountains (*n*=100)
Northern oriole (*Icterus galbula*)	0	0	1	93
Hooded oriole (*I. cucullatus*)	0	1	0	0
Scott's oriole (*I. parisorum*)	6	23	37	0
Western tanager (*Piranga ludoviciana*)	45	33	3	36
Summer tanager[b] (*P. rubra*)	0	6	2	0
Hepatic tanager[b] (*Piranga flava*)	7	66	12	0
White-crowned sparrow (*Zonotrichia leucophrys*)	0	0	0	17
Lark sparrow (*Chondestes grammacus*)	0	0	0	14
Black-chinned sparrow (*Spizella atrogularis*)	0	0	12	0
Chipping sparrow (*S. passerina*)	0	3	10	37
Fox sparrow (*Passerella iliaca*)	0	0	0	1
Rufous-sided towhee (*Pipilo erythrophthalmus*)	27	59	29	30
Green-tailed towhee (*P. chlorurus*)	0	0	1	0
Black-headed grosbeak (*Pheucticus melanocephalus*)	52	91	7	91
Yellow grosbeak (*P. chrysopeplus*)	0	0	1	0
Lazuli bunting (*Passerina amoena*)	1	2	0	16
Purple finch (*Carpodacus purpureus*)	0	0	0	19
Cassin's finch (*C. cassinii*)	2	2	0	1
American goldfinch (*Carduelis tristis*)	0	0	0	1
Lesser goldfinch (*C. psaltria*)	0	0	0	67
Lawrence's goldfinch[c] (*C. lawrencei*)	0	0	0	76
Pine siskin (*C. pinus*)	1	1	0	2

[a] Total number of counting stations sampled.
[b] Geographic range does not extend to Tehachapi Mountains.
[c] Geographic range does not extend to southeastern Arizona mountains.

foraging. Also, these neotropical migratory birds have additional activities (e.g., nesting, perching, roosting) that may require oaks. As these activities are studied in greater detail, our realization of the importance of oaks may become even greater.

Thus, oaks provide a number of critical resources for many species of neotropical migratory birds in the Southwest. As the conservation of neotropical birds is becoming increasingly important, it is critical to understand the relationships between oaks and habitat needs of these birds. Only with such knowledge can resource managers provide appropriate conditions required by these species.

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LITERATURE CITED

Balda, R.P. 1967. Ecological relationships of the breeding birds of the Chiricahua Mountains, Arizona. Ph.D. dissertation, University of Illinois, Urbana. 218 pp.

Block, W.M. 1989. Spatial and temporal patterns of resource use by birds in California oak woodlands. Ph.D. dissertation,

University of California, Berkeley. 364 pp.

Block, W.M. 1990. Geographic variation in foraging ecologies of breeding and nonbreeding birds in oak woodlands. Studies Avian Ecology 13:264-269.

Block, W.M. 1991. Foraging ecology of Nuttall's woodpecker. Auk 108:303-317.

Table 4. – Percent use of oaks by neotropical migratory birds found on the insular mountains of southeastern Arizona during the 1991 breeding season.

Species	n[a]	% Oak Total	 Arizona white	 Silverleaf	 Emory	 Gambel
Hermit thrush	23	17.4	17.4			
Yellow-rumped warbler	19	36.8		10.5	10.5	15.8
Black-throated gray warbler	99	73.7	29.3	30.3	13.1	1.0
Painted redstart	75	48.0	14.7	30.7	1.3	1.3
Red-faced warbler	85	43.5	7.1	24.7	1.1	10.6
Grace's warbler	58	32.7	6.9	24.1	1.7	
Virginia's warbler	32	34.4	6.3	21.9	3.1	3.1
Hepatic tanager	28	35.8	14.3	14.3	3.6	3.6
Black-headed grosbeak	90	52.2	23.3	17.8	7.8	3.3

[a] Sample size.

Block, W.M., and M.L. Morrison. 1991. Influence of scale on the management of wildlife in California oak woodlands. Pages 96-104 in R. B. Standiford, tech. coord. Proceedings of the symposium on oak woodlands and hardwood rangeland management. USDA Forest Service Gen. Tech. Rep. PSW-126. Pacific Southwest Forest and Range Experiment Station, Berkeley, CA. 376 pp.

Block, W.M., M.L. Morrison, and J. Verner. 1990. Wildlife and oak-woodland interdependency. Fremontia 18:72-76.

Cochran, W.G. 1977. Sampling techniques, Third Edition. Wiley and Sons, New York, NY. 413 pp.

Finch, D.M. 1991. Population ecology, habitat requirements, and conservation of neotropical migratory birds. USDA Forest Service Gen. Tech Rep. RM-205. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 26 pp.

Gauthreaux, S.A. Jr. 1991. Preliminary lists of migrants for the Neotropical Migrant Bird Conservation Program. Unpubl. mimeo. 3 pp.

Hutto, R.L. 1985. Seasonal changes in the habitat distribution of transient insectivorous birds in southeastern Arizona: competition mediated? Auk 102:120-132.

Jaccard, P. 1912. The distribution of flora in the alpine zone. New Phytologist 11:37-50.

Lamb, S.H. 1989. Woody plants of the Southwest. Sunstone Press, Santa Fe, NM. 177 pp.

Marascuilo, L.A., and M. McSweeny. 1977. Nonparametric and distribution-free methods for the social sciences. Brooks-Cole, Monterey, CA. 556 pp.

Marshall, J.T. 1957. Birds of the pine-oak woodland in southern Arizona and adjacent Mexico. Pacific Coast Avifauna 32:1-125.

Reynolds, R.T., J.M. Scott, and R.A. Nussbaum. 1980. A variable circular-plot method for estimating bird numbers. Condor 82:309-313.

SWCA. 1991. Neotropical migrant birds in Region 3 - status of knowledge in 1991. Unpubl. rep. 82 pp.

Verner, J. 1985. Assessment of counting techniques. Current Ornithology 2:247-302.

Hydrology and Watershed Management of Oak Woodlands in Southeastern Arizona [1]

Vicente L. Lopes and Peter F. Ffolliott[2]

Abstract.–Interactions among hydrological processes, the soil-vegetation complex, and management practices in oak woodlands of southeastern Arizona have not been investigated thoroughly. One reason for this omission is the scarcity of measurements of storm runoff, soil erosion, and sediment yield from these areas. This paper summarizes climatic and soils data representative of oak woodlands in southeastern Arizona, examines watershed management issues, and introduces and discusses the hydrological and sediment processes common to dryland environments with similar characteristics to oak woodlands.

INTRODUCTION

Oak woodlands, as other vegetative systems in dryland environments, are ecological systems that are sensitive to climatic fluctuation and human impact. They are water limited, and, therefore, knowledge of the role of water is essential in understanding soil-vegetation relationships that are significant in promoting stability of the landscape, and in mobilizating and transporting sediment downstream. This role of water is especially important when considering potential global climate changes, which can disrupt some of unappreciated equilibria between soils, soil moisture, vegetation, drainage channels and networks, and streamflow responses to precipitation.

Despite the areal extent and environmental importance of oak woodlands in the southwestern United States and northern Mexico, few hydrological studies have been conducted in the area. Even rudimentary information concerning measurements of infiltration, evapotranspiration, runoff, soil erosion, sediment transport, and water quality parameters are not available. This paper summarizes the current knowledge of hydrology and watershed management of oak woodlands in southeastern Arizona, and concludes by considering important topics for future hydrological research.

HYDROLOGY

Hydrological characteristics of the oak woodlands can be presented only in broadly-stated terms. In the section that follows, therefore, general descriptions of climatic and hydrological regimes, including soil characteristics and erosion processes, are presented.

Precipitation

Oak woodlands of Arizona receive in excess of 467 mm of annual precipitation on the average. Extremes in annual precipitation range from 373 to nearly 600 mm (Sellers and Hill 1972). About one-half of the annual precipitation falls in summer thunderstorms, particularly in July through early September. These precipitation events are generally high intensity, short duration convectional storms that originate in the Gulf of Mexico. Winter precipitation, mostly rain but occasionally snow, comes normally in November through early April. Moisture for winter precipitation typically comes in frontal storms from the Pacific Ocean. When it occurs, snow only persists on the ground for relatively short periods of time.

Precipitation plays a double role in oak woodlands of Arizona. First, it supplies soil moisture to promote vegetative ground cover which tends to reduce soil erosion. At the same time, it is the source for overland flow from both the vegetated and nonvegetated areas, and a cause of erosion. Studies by Langbein and Schumm (1958) suggested that these influences reach a balance, depending largely upon the accompanying temperature regime, with an annual precipitation of between 380-510 mm. On a regional basis, erosion increases as rainfall increases to about 380-510 mm per year, and then declines as vegetation becomes more dominant with higher rainfall amounts.

Temperature

Mean annual temperature in the oak woodlands of southeastern Arizona is about 15.7°C. This estimate is based on an average of 25 years of temperature records from eight weather stations in southeastern Arizona, located in the elevational range of the oak woodlands (Sellers and Hill 1972). Frost-free days vary from 140 to 200, depending largely upon the latitude and elevation of the site.

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Evaporation

Evaporation from free-water surfaces and the soil surface is an important feature of the water balance in oak woodlands. Its determination is required in quantification of water balance under existing management practices and proposed alternatives. Oak woodlands annually lose about, 1690 mm of free-water surface evaporation on the average (Cooley 1970). Extremes in annual evaporation from free-water surfaces ranges from 1563 to nearly 1750 mm. The evaporation component of evapotranspiration in oak woodlands of Arizona conforms, in general, with the expectancy indicated for bare-soil evaporation. Modifying factors are introduced by the physical presence of the vegetation, through shading, windbreak effects, and the influence of water extraction by plant roots.

Interception and Throughfall

The interception of throughfall of precipitation by vegetation results in the incoming precipitation being partitioned into three components; part is retained on the foliage, part is channeled down the branches and stems, and part drips off from the branches. Runoff is also modified because of the altered intensity and distribution characteristics and the improved soil permeability caused by the presence of the vegetation. This particularly applies to the portion of the precipitation which is channeled down the trunks of the trees since root density and soil permeability are highest in this zone. In oak woodlands, this is of special importance since it concentrates water and raises the chances of deep infiltration.

A study of rainfall distribution in the oak woodlands of southeastern Arizona reported that up to 70 percent of the late summer-early fall rainfall is intercepted directly under the canopies of Emory oak trees (Haworth and McPherson 1991). Little differences in precipitation were observed between the edge of the canopies and tree-free locations. Throughfall varied from 100 percent (all trees, large storms) to about 30 percent (large trees, small storms). Small Emory oak trees affected rainfall distribution only during small storms of relatively limited duration. Larger trees affected rainfall during larger storms up to about one inch depth. Rainfall was distributed evenly under and around trees in storms generally larger than one inch. Snowfall interception has not been measured in the oak woodlands. However, loss of water through this interception process likely is minimal because of limited snowfall events.

Infiltration

Soils in the oak woodlands of southeastern Arizona are typified, in general, by those found in the San Rafael Valley and Canelo Hills. The Casto-Martinez-Canelo association is the dominant soil in the San Rafael Valley (Hendricks et al. 1985). These soils, formed in old alluvia developed largely on parent materials of mixed sedimentary and igneous rocks, are deep, moderately fine to very finely textured, gravely, and, characteristically, have moderate rates of infiltration. These soil features collectively affect the amount of surface runoff produced.

In addition to the Casto-Martinez-Canelo association, the haplustolls-lithic-agriustolla- rock outcrop association make up the soils of Canelo Hills (Hendricks et al. 1985). These soils are shallow, moderately fine to moderately course in texture, gravely and cobbly, and also have moderate rates of infiltration. Soils supporting oak woodlands in southeastern Arizona often have a layer that impedes the downward movement of water, further influencing the pathways of water flow through these ecosystems.

Surface Runoff

Most of the rain falling on dryland environments such as oak woodlands of Arizona is intercepted by vegetation, absorbed by the porous mantle of soil and rock waste, or lost by evaporation. The intensity of rainfall, in general, is more important than the total amount of rainfall in producing runoff. However, total runoff can increase with duration of the rainfall event.

Surface runoff measurements have not been taken on watersheds located within the oak woodlands of southeastern Arizona. However, there are plans by the University of Arizona to instrument a catchment in the Huachuca Mountains to measure surface runoff regimes, sediment rates, and water quality constituents that are representative of these woodlands. A pre-calibrated control section and a continuous water-stage recorder will be installed as a first step in a long-term environmental monitoring effort. It is possible that information obtained in this monitoring effort can be incorporated into an international geosphere-biosphere monitoring network (Eddy et al. 1991) to investigate the importance of global environmental change. In the mean time, as a first approximation, it might be possible to obtain estimates of surface runoff from measurements made in other woodland types in Arizona.

Surface runoff that occurs in the oak woodlands is produced by both rainfall and snowmelt events. Rainfall events occur most commonly in relation to the high intensity, short duration summer thunderstorms that occur in July through early September. Depending upon rates of overland flow, these events can accelerate erosion and sedimentation. Much of the snowmelt runoff originates at higher elevations, where snow accumulations throughout the winter can result in significant melt in the spring. In general, durations of surface runoff events from snowmelt are longer than those observed from rainfall.

Much of the surface runoff originating in the mountain forests at higher elevations in southeastern Arizona flows in stream channels through oak and associated woodlands on route downstream. It is important, therefore, that watershed management practices protect these lands, along with the oak woodlands, from accelerated erosion and sedimentation which will impact not only water quality but be detrimental to long-term site productivity.

Erosion and Sediment Yield

Sediment yields from oak woodlands of Arizona are largely unknown. However, as in the case of surface runoff, it might be possible to obtain estimates of these sediment yields from measurements made in other woodland types in Arizona. In the pinyon-juniper woodlands, a type that frequently intermingles with the oak woodlands of southeastern Arizona (Lowe 1964), it appears that annual sediment yields of 1 to 2 tons per acre are approaching the maximum sediment loss potential (Clary et al. 1974). There also appears to be little meaningful change in sediment yields after conversion treatments. Exceptions to these findings have been reported for "historically large" hydrological events in pinyon-juniper woodlands.

Chaparral brushlands are mixed with oak woodlands on the flanks of isolated mountain ranges in southeastern Arizona (Lowe 1964). Sediment yields from chaparral watersheds are generally of the same order of magnitude as those in pinyon-juniper woodlands. However, sediment production can be accelerated immediately after conversion treatments, especially fire (Hibbert et al. 1974).

Sediment yields in the pinyon-juniper woodlands and chaparral brushlands are related to the magnitudes of overland flow and stabilities of stream channels, particularly in the lower portions of watersheds. Similar situations likely are found in the oak woodlands of southeastern Arizona.

In general, rates of sediment transport in stream channels in oak woodlands are controlled by a number of noteworthy phenomena characteristic of these lands. These phenomena are high intensity thunderstorms, which can result in large peak discharges per unit area; limited areal extent rainfall, which can result in partial area runoff; transmission losses on normally dry stream beds, which can result in decreases in sediment transport capacities in the downstream direction; generally steep channels, which can result in high flow velocities with increased potential for transporting more sediment; and unconsolidated stream bed material and unprotected stream banks, which can enhance sediment supplies or sources.

HYDROLOGICAL MODELING

Most hydrologists and decision-makers agree about the importance of models in helping to solve problems related to the environment and its resources; this can be seen in the steady increase in the number of publications in the topic in major professional journals and technical reports. Models and modeling, as well as systems which the models describe or represent, are terms which are extensively used and may have different meaning to different people. Models can be divided into two categories: physical models and abstract models. Physical models include scale models and analog models. Scale models represent the system or process under investigation on a reduced scale, such as a hydraulic model of a dam spillway. Analog models use another system or process having properties similar to those of the prototype. Abstract models represent the system or process in mathematical form. The system operation is described by a set of equations linking the input and the output variables. These variables can be functions of space and time, and they can also be probabilistic or random variables. The purpose of this section is to discuss some of the distinct characteristics of hydrological models and their potential for helping to solve problems related to watershed planning and management.

Stormflow Models

By far the most popular empirical model for storm runoff prediction is the Curve Number (CN) method (Soil Conservation Service 1972), originally developed by the USDA Soil Conservation Service (SCS) for use in conservation planning and engineering design, mostly in croplands. Curve number values required to apply the method are available for a limited variety of soils and vegetative types. There are no CN values for oak woodlands. A step towards testing of this approach would be to determine Curve Numbers values for oak watersheds from local rainfall and runoff data obtained from instrumented watersheds in oak woodlands in southeastern Arizona.

The kinematic wave approach, a major component of physically-based hydrological models for arid and semiarid environments, is a widely used method to simulate the movement of rainfall excess water over the land surface and through small channels and, as such, is an alternative modeling approach to the empirical Curve Number method. Although the kinematic wave method requires simplifying assumptions compared to more complete theory, its hydraulic requirements are well established (Wooding 1965; Woolhiser and Liggett 1967) and has been extensively verified by experiment (Rovey and Woolhiser 1977, Woolhiser et al. 1990). Its testing and application to oak woodlands will depend largely upon data gathering and analysis from carefully designed field experiments with both natural and simulated rainfall conditions. This approach further requires a geometrical representation of actual watersheds, which usually are represented by a simplified configuration consisting of sequences (cascade) of overland flow planes discharging into channel elements. Each plane or channel element must be characterized by a length, width, slope, hydraulic conductivity parameter, and a roughness parameter. For channel elements, a cross-section geometry also is needed.

Erosion and Sediment Yield Models

Existing erosion and sediment yield prediction models with potential for application in oak woodlands of Arizona include the empirical Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978), the Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1989), and the physically-based SPUR (Simulation of Production and Utilization of Rangelands) (Wight 1983; Wight and Skiles 1987), and the Water Erosion Prediction Project (WEPP) models (Lane and Nearing 1989).

The USLE is the modeling technology most widely used today to predict long-term average annual soil loss from interrill (sheet erosion) and rill areas. Despite its widespread use and the breadth of experience which it incorporates, the USLE is empirically based on data gathered from uniform slope test plots and, unfortunately, does not incorporate explicitly the processes of detachment and deposition by surface flow in rill areas. Several modifications of the USLE have been proposed to overcome its empirical limitations (Renard et al. 1974; Williams 1975; Renard et al. 1989). However, all of these modifications do not eliminate the primary limitations of the USLE to consider detachment by surface flow processes, severe rilling or gully erosion, and sediment deposition.

Since the USLE was not satisfactory in estimating erosion, the more recent RUSLE, a revision of the USLE, was undertaken by a the USDA Agriculture Research Service (ARS). Although this effort is nearing completion, there still will be a need for continuing efforts by hydrologists to address the question arising from use of the equation on forest and woodlands.

The SPUR model is a product of the ARS efforts to develop a model for use in rangeland resource planning. The model provides a basis for management decisions by predicting runoff, erosion as well as herbage yields and livestock production. Sediment loads are separated into suspended particles (sizes less than 0.062 mm in diameter) and bed load (sizes greater than 0.062 mm). Only the bed material has a particle size distribution associated with it. Bed load (assumed at transport capacity condition) is computed with a modified Duboy's equation. Suspended load is determined from a modified Bagnold equation (Lane 1982).

The WEPP (Water Erosion Prediction Project) also is a product of the ARS (Lane et al. 1988). The effort involves three separate model versions: hillslope, watershed, and grid models. The WEPP hillslope model is nearing completion. Testing by action agencies undoubtedly will require additional refinement and/or new algorithms to better describe some of the processes being simulated. The WEPP hillslope model computes sheet and rill erosion associated with overland flow and sprinkler irrigation. The WEPP modeling technology is applicable on croplands, rangelands, and disturbed forest lands. Procedures are limited to areas where the hydrology is dominated by Hortonian overland flow and should not be applied where partial area response hydrology and subsurface flow dominate.

Although modeling technologies such as RUSLE, SPUR, and WEPP might be soon used for prediction of erosion and sediment yield from oak woodlands, many assumptions associated with the mathematical formulations in these models are in need of refinement. Also, there are additional problems which the models need to address using better research knowledge to enhance overall model utility. These modeling technologies do not have the capability of dealing with the spatial and temporal variability of the erosion and flow processes encountered on oak woodland watersheds. Erosion and sediment prediction in oak woodlands requires a modeling technology that begins with the description of soil detachment process by raindrop impact and runoff, and accounts for the spatial and temporal variability of the flow and sediment transport capacity as the sediment moves downstream from its point of origin. Equally important is that application of this modeling technology has the capacity to predict erosion and sediment yield under current and alternative management conditions in order to identify the underlying causes of the erosion and sediment damages, determine the sources of erosion and sediment causing such damages, and formulate cost-effective erosion and sediment control measures.

WATERSHED MANAGEMENT

Management of watersheds in oak woodlands includes considerations of forestry, livestock production, wildlife habitats, recreational use, and soil and water resources. Conservation of soil and water resources is of particular importance in the oak woodlands because of the fragile nature of the soils and limited amounts of available water. Watershed management practices, therefore, are planned to ensure protection and, where possible, enhancement of soil and water.

Soil and Water Conservation

Concerns of soil and water conservation in the oak woodlands are related largely to accelerated erosion and sedimentation. Therefore, watershed management practices which maintain healthy, well-stocked stands of trees and a cover of herbaceous plants to protect against increased erosion and sedimentation are encouraged. Engineering structures, for example, check dams and other forms of retention structures, also are used on sites with potentially severe problems.

There is a question of whether the amounts of erosion and sedimentation in oak woodlands are influenced by land management practices, particularly grazing by livestock. Unfortunately, information necessary to answer this question is incomplete. However, results from studies conducted in the adjacent and intermingling pinyon-juniper woodlands might be helpful.

Much of the severe erosion and sedimentation observed in pinyon-juniper woodlands has been associated to periods of overgrazing by livestock, largely in the past. With more controlled grazing practices in recent years, this situation likely has improved. Nevertheless, Evans (1988) reported that over 80% of the woodlands in the western United States still are grazed by livestock, with these woodlands supporting between 1 and 1.5 million animal unit months of grazing. It is important, therefore, that grazing of livestock in these woodland types, including the oak woodlands of southeastern Arizona, be practiced in a manner that minimizes the possibilities of increasing erosion and sediment yield.

Watershed Management Practices

Practices associated with watershed management in the woodlands of the southwestern United States and northern Mexico can be grouped into three categories: practices which minimize adverse impacts to soil and water resources, those that are designed to increase water yields, and rehabilitation practices that are needed to bring a watershed from a poor, mismanaged condition into a productive state (Ffolliott 1988). Within the framework of these categories, watershed management problems and practices in the oak woodlands of southeastern Arizona are described below.

Minimize Adverse Impacts

Because of the fragile character of the soil and water resources in the oak woodlands, extreme care must be exercised to protect these resources from deterioration. In general, degradation of soil and water resources in woodland ecosystems of the southwestern United States and northern Mexico is associated mostly with precipitation events of "historically" high intensities and large amounts. Nevertheless, to ensure protection of these necessary resources, various preventative and control measures are incorporated into watershed management programs.

Managerial practices that minimize adverse impacts to soil and water resources in these ecosystems are similar to those used to prevent excessive rates of erosion. For example, roads are not constructed in or near stream channels. When roads are closed to travel by the public, roadways are seeded with herbaceous plant species to protect against erosion. Harvesting of fuelwood and other wood products is restricted in periods of excessive rainfall. Grazing of livestock is monitored to ensure minimal effects on the ecosystem. These activities are components of integrated watershed management programs that are multiple use in nature.

Increase Water Yields

Vegetative management on upstream watersheds is one approach to increasing water yields. Experiments conducted throughout the world have demonstrated that water yields can be increased, to varying magnitudes and durations, by changing the structure and composition of the vegetative cover on a watershed (Bosch and Hewlett 1982). The additional streamflow runoff is attributed, in most instances, to decreased transpiration. That is, following treatment, less precipitation is converted into vapor as a result of rainfall interception, and more is available for streamflow runoff.

It is unlikely that the oak woodlands of southeastern Arizona have a high potential for water yield improvement through manipulation of vegetative cover. Although not investigated directly, it is probable that the relatively high evapotranspiration demands in relation to the precipitation inputs in these ecosystems precludes much change in water yield from vegetative management practices.

Rehabilitation

Management practices to rehabilitate watersheds also are implemented in the woodlands of the southwestern United States and northern Mexico. Among activities that are undertaken in this regard are the control of gullies and mass wasting through the construction of upstream check dams, establishment of a protective tree, shrub, or herbaceous cover on eroded and degraded sites, and, when necessary, curtailment of wood harvesting, livestock grazing, and other exploitative practices. Rehabilitative practices are observed on public and privately owned lands in southeastern Arizona.

Because woodland ecosystems, once degraded, are difficult to rehabilitate, a managerial emphasis generally is placed on incorporating practices which minimize adverse impacts to soil and water resources into the planning of watershed management programs. By doing so, "chain-reactions" that occur from an initial loss of soil and water resources to advanced states of degradation, in which the overall productivity is minimal, can be averted.

RESEARCH OPPORTUNITIES

Hydrological research opportunities in oak woodlands of southeastern Arizona are nearly limitless. Of urgent necessity is the need to develop a modeling technology to evaluate the effects of human impacts on runoff and sediment response from watersheds. Such initiatives require that the relevant and interrelated plant, soil, and water processes be understood. Knowledge of local processes as infiltration, percolation, evapotranspiration, runoff generation, hydrograph development, soil erosion, and sediment yield are important and of interest to the sustainable development of the oak woodlands. For example, a decrease in total precipitation caused by a climatic change can cause a decrease in vegetative growth, which in turn can cause an increase in runoff, erosion, sediment yield and water pollution from the site. The increase in runoff and erosion may in turn decrease future vegetation growth, starting a new cycle of ecosystem degradation, and relocation of associated plant communities.

A distributed modeling system integrating the weather, soil, vegetation, hydrological, and erosional subsystems can be useful in assessing the effects of climate change, human impact, and variability on the stability of oak woodlands. The model system also will help decision-makers to assess the potential effects, given the uncertainties regarding future land surface conditions. The modeling system will enhance the identification of fruitful future research areas, and highlight areas where additional information is needed.

A sequence of steps leading towards the development of a modeling technology to assist decision-makers in evaluating the impacts of management practices on oak woodland watersheds is presented below. The goal of this modeling approach is the development of a methodology for planning, implementing, and monitoring integrated management of natural resources for conservation and sustainable development of watershed lands. The following steps should be undertaken:

1. Establishment of nested groupings of instrumented watersheds to obtain baseline parameters and variables for evaluating the interactions between weather, soil, and vegetation and their effects on hydrological and sediment processes.
2. Development of a conceptual modeling framework, formulation of mathematical equations and appropriate boundary conditions describing the relevant physical and biological processes of interest, and implementation of mathematical models into computer simulation models. The simulation models should be structured to allow evaluation of the adjustments through time of watershed response to land use changes and the potential for implementing corrective measures and management practices which could minimize adverse impacts.
3. Development of model parameter estimation methods using rainfall, runoff, topographic, soil, and vegetation data from instrumented watersheds.
4. Simulation of long-term daily and sub-daily weather data, consistent with local observed statistical properties. A stochastic weather generator (Fogel et al. 1974; Nicks and Lane 1989) could be used as a first approximation for generation of daily sequences of precipitation and temperature. Daily rainfall disaggregation into multiple discrete events could be done with the methods of Nicks and Lane (1989) or Hershenhorn and Woolhiser (1987).
5. Initiation of simulation studies of the impacts of human activities on vegetative growth and cover, and soil protection; runoff processes (generation, volume and peak flow); and erosion and sediment delivery rates. Simulations also would be made on the impacts of erosion on native soil productivity and fertility.
6. Demonstration of the potential of simulation models in assisting decision-makers to evaluate management practices for preventing soil deterioration and system degradation of oak woodlands. From the simulation results, an array of potential effects caused by land management practices could be generated and examined. Environmental conditions where adverse effects are likely to occur could be identified. The simulation results also could help in both mitigating and monitoring changing climate and human effects by identifying sensitive areas.

LITERATURE CITED

Bosch, J. M., and J. D. Hewlett. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. Journal of Hydrology 55:3-23. Clary, W. P., M. B. Baker, Jr., P. F. O'Connell, T. N. Johnsen, Jr., and R. E. Campbell. 1974. Effects of pinyon-juniper removal on natural resource products and uses in Arizona. USDA Forest Service, Research Paper RM-128.

Cooley, K. R. 1970. Evaporation from open water surfaces in Arizona. Agricultural Experiment Station, The University of Arizona, Folder 159.

Eddy, J. A., T. F. Malone, J. J. McCarthy, and T. Rosswall. 1991. Global change systems for analysis, research and training. IGBP Global Change Report 15.

Evans, R. A. 1988. Management of pinyon-juniper woodlands. USDA Forest Service, General Technical Report INT-249.

Ffolliott, P. F. 1988. Arid zone forestry program: State of knowledge and experience in North America. Arizona Agricultural Experiment Station, Technical Bulletin 264.

Fogel, M.M., L. Duckstein and J.L. Sanders. 1974. An event-based stochastic model of areal rainfall and runoff. Proc. of Symp. on Statistical Hydrology. USDA-ARS, Misc. Pub. No. 1275, pp. 247-261.

Haworth, K., and G. R. McPherson. 1991. Effect of *Quercus emoryi* on precipitation distribution. Journal of the Arizona-Nevada Academy of Science: Proceedings Supplement 1991:21.

Hershenhorn, J. and D.A. Woolhiser. 1987. Disaggregation of daily rainfall. Journal of Hydrology 95(1987):299-322.

Hibbert, A. R., E. A. Davis, and D. G. Schroll. 1974. Chaparral conversion potential in Arizona. Part I: Water resources and effects on other resources. USDA Forest Service, Research Paper RM-126.

Hendricks, D. M., P. R. Krausman, R. W. Mannan, F. D. Hole, H. W. Pierce, S. L. Levine, D. F. Post, C.

W. Guernsey, Y. H. Havens, J. E. Jay, and M. L. Richardson. 1985. Arizona soils. College of Agriculture, University of Arizona, Tucson, Arizona.

Langbein, W.B. and S.A. Schumm. 1958. Yield of sediment in relation to mean annual precipitation. Trans. AGU 39:1076-1084.

Lane, L. J. 1982. Development of a procedure to estimate runoff and sediment transport in ephemeral streams. In: Walling D.E. (ed.). 1982. Recent developments in the explanation and prediction of erosion and sediment yield. IAHS Publ. No. 137, pp. 275-282.

Lane, L. J. and Nearing, M. A. (eds.). 1989. USDA - Water Erosion Prediction Project:
Landscape Profile Model Documentation. USDA-ARS, NSERL Report No. 2, West Lafayette, Indiana.

Lane, L. J., Schertz, D. L., Alberts, E. E., Laflen, J. M. and Lopes, V. L. 1988. The US national project to develop improved erosion prediction technology to replace the USLE. In: Proc. of the IAHS Int. Symp. on Sediment Budgets in Porto Alegre, Brazil, December 11-15, 1988, Publ. No. 174 (1988), pp. 473-481.

Lowe, C. H. 1964. Arizona's natural environment. University of Arizona Press, Tucson, Arizona.

Nicks, A.D. and L.J. Lane. 1989. Weather generator. In: Lane, L. J. and Nearing, M. A. (eds.). 1989. USDA - Water Erosion Prediction Project: Landscape Profile Model Documentation. USDA-ARS, NSERL Report No. 2, West Lafayette, Indiana.

Renard, K. G., Foster, G. R., Weesies, G. A., and Porter, J. T. 1989. RUSLE: The revised universal soil loss equation. Paper presented at the SWCS Annual Meeting, August 1989, Edmonton, Alberta, Canada.

Renard, K. G., Simanton, J. R., and Osborn, H. B. 1974. Applicability of the universal soil loss equation to semiarid rangeland conditions in the southwest. Hydrology and Water Resources in Arizona and the Southwest 4:18-31.

Rovey, E. W. and Woolhiser, D. A. 1977. Urban storm runoff model. Journal of the Hydraulic Division, ASCE, 103(HY11):1339-1351.

Sellers, W. D. and Hill, R. H. (eds.). 1972. Arizona climate 1931-1972. 2nd edition. The University of Arizona Press, Tucson, Arizona.

Soil Conservation Service 1972. National Engineering Handbook, Section 4, Hydrology.

U. S. Department of Agriculture, Washington, D.C.

Wight, J. R., and Skiles, J. W., (Editors). 1987. SPUR - Simulation of Production and Utilization of Rangelands. Documentation and user guide. USDA-ARS, ARS-63.

Wight, J. R., (Editor). 1983. SPUR: Simulation of Production and Utilization of Rangelands: a rangeland model for management and research. USDA-ARS Misc. Publ. No. 1431.

Williams, J. R. 1975. Sediment-yield prediction with universal equation using runoff energy factor. In: Present and Prospective Technology for Predicting Sediment Yields and Sources, Proc. of Sediment-yield workshop, USDA, Oxford, Mississippi, pp. 244-252.

Wischmeier, W. H., and Smith, D. D. 1978. Predicting rainfall erosion losses - a guide to conservation planning. USDA Agricultural Handbook No. 537, Washington, D.C.

Wooding, R. A. 1965. A hydraulic model for the catchment-stream problem. I. kinematic wave theory. Journal of Hydrology 3:254-267.

Woolhiser, D. A., Smith, R. E. and Goodrich, D. C. 1990. KINEROS, a kinematic runoff and erosion model: documentation and user manual. USDA-ARS, ARS-77.

Woolhiser, D. A., and Liggett, J. A. 1967. Unsteady, one-dimensional flow over a plane - the rising hydrograph. Water Resources Research, 3:753-771.

Ecology and Management of the Southwestern Pinyon-Juniper Woodlands[1]

Gerald J. Gottfried[2]

Abstract.–Pinyon-juniper woodlands cover large areas of Arizona and New Mexico. Management of these lands is shifting from a single-resource emphasis to recognizing the value of the woodlands for a number of valuable resources. Proper management for combinations of fuelwood, range, wildlife, and recreation must be based on sound ecological information. While the information is incomplete, this paper attempts to describe our current knowledge of the ecology (primarily of the tree species) and management of the pinyon-juniper woodland ecosystem.

INTRODUCTION

The pinyon-juniper woodland ecosystem covers extensive areas of the western United States. The management philosophy toward these lands has been inconsistent over the last 100 years. The woodlands often were viewed as having marginal values and treated with benign neglect, or they were viewed as an impediment to efficient livestock production and eradicated in favor of herbaceous forage species. Currently, land managers are beginning to recognize the potential value of pinyon-juniper woodlands for yields of multiple resources (such as wood products, wildlife habitat, livestock forage production, and recreation), and are adjusting management strategies accordingly. This new approach to woodland management should be based on sound scientific information. Unfortunately, our knowledge of the ecology of these woodlands, and the impacts of the range of management options, is still incomplete. This paper will describe what is known about the ecology of the southwestern pinyon-juniper woodlands and some of the current management options. The ecology of the principal tree species will be emphasized.

PINYON-JUNIPER WOODLAND CHARACTERISTICS AND RESOURCES

Characteristics

One of the main reasons for the interest in the pinyon-juniper woodlands is because they cover such a large part of the western United States – approximately 47 million acres (Evans 1988). A variety of other estimates appear in the literature, but differences are generally related to how marginal juniper lands have been defined. A recent survey of forest resources in Arizona indicated that there are about 9 million acres of pinyon-juniper and 2 million acres of relatively pure juniper (Conner et al. 1990). The two categories, which will be considered together for this presentation, account for approximately 56% of the total forest land in Arizona (Conner et al. 1990). Fowler et al. (1985) reported that about 10 million acres of pinyon-juniper woodland in New Mexico, equivalent to 14% of the state, can be considered manageable using criteria of density and quality. The remaining pinyon-juniper lands did not qualify as having a potential for economic management.

The pinyon-juniper woodland ecosystem is not homogeneous. Moir and Carleton (1987) have identified 70 pinyon-juniper plant associations and 280 ecological sites in Arizona and New Mexico. The woodlands in the Southwest usually are found at elevations from 4,500 to 7,500 feet, where precipitation ranges from 12 to 22 inches (Springfield 1976). The woodlands grade into grasslands, brush-dominated vegetation, and oak woodland zones on drier sites at lower elevations. The woodlands grade into ponderosa pine (*Pinus ponderosa*) forests at the higher elevations.

Woodlands are found on soils derived from different parent materials and classified, at the soil order level, as Aridisols, Entisols, Mollisols, Vertisols, Alfisols, and Inceptisols (Evans 1988). The soils generally are characterized as being shallow, well-drained, and having low fertility, although exceptions occur.

Resources

Although many people traditionally have viewed the woodlands as having minimal commercial value, they do provide many resource values. The pinyon-juniper woodlands have been used by Native Americans since prehistoric times for construction timber, fuelwood, pinyon nuts, medicines, ceremonial items, and a place to hunt and gather food. Most of the prehistoric archeological sites in the Southwest are concentrated in the pinyon-juniper zone because of the availability of resources and the moderate climate. The woodlands are the dominant vegetation type on many reservations and therefore are important for the Native American communities of Arizona and New Mexico.

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The early European colonists relied on the woodlands for many of the same products as the Native Americans. The Spanish introduced livestock during the sixteenth century. Livestock production is still an important use of the land. Evans (1988) reported that over 80% of the woodlands in the West are grazed by livestock, supporting between 1 and 1.5 million animal unit months of grazing. Following World War II, large areas of woodland were indiscriminately cleared of trees in the hope of stimulating forage production. These activities were based on the observation that herbage yields declined as tree canopy cover increased (Arnold et al. 1964). However, Clary et al. (1974) determined that many of these treatments did not produce or sustain the desired forage increases and were difficult to justify economically.

Fuelwood always has been an important resource from these lands. However, the demand for fuelwood has increased since the 1973 oil embargo; Ffolliott et al. (1979) found a 400% increase in wood usage in five Arizona markets between 1973 and 1978. Approximately 8.1 million cubic feet of pinyon and juniper fuelwood were harvested in Arizona in 1984 (McLain 1988). Several Native American communities depend upon the commercial sale of fuelwood as a source of general income and of work for individual tribal members. Some of the national forests that are located near population centers are concerned that demand will exceed supply within the next 50 years.

Another traditional product has been pinyon nuts. Approximately 1 to 2 million pounds of nuts are gathered annually for personal and commercial consumption (Barger and Ffolliott 1972). Nut collecting is also an important recreational use of the woodlands. Many people prefer pinyon Christmas trees, which usually are cut as part of a family recreational activity.

The woodlands have a low potential for water yield improvement by manipulating the vegetation because of relatively high evapotranspiration demands (Clary et al. 1974, Hibbert 1979). This was confirmed by paired watershed experiments at Beaver Creek, Arizona, and other locations (Clary et al. 1974). However, much of the surface runoff originating in higher elevation ponderosa pine and mixed conifer forests flows through the woodlands en route to downstream agricultural, municipal, and industrial users. Watershed management practices must protect the land from accelerated erosion, which not only will impact water quality but be detrimental to site quality and long-term site productivity. This problem can be particularly acute in nutrient-poor ecosystems, such as the woodlands.

Wildlife depend on the pinyon-juniper woodlands for both seasonal and permanent habitat use. Many animals move into the woodlands during the winter to escape the harsh environment in the higher elevation forests. These lands provide shelter and food for a large number of game and nongame species, including some sensitive species. Hunting and birding are traditional recreational activities linked to the wildlife resource.

ECOLOGY OF THE PINYON-JUNIPER WOODLANDS

General Species Characteristics

The Colorado pinyon (*Pinus edulis*) is the common denominator in most pinyon-juniper stands in the Southwest. In areas south of the Mogollon Rim in Arizona, it is replaced by a single-needle pinyon, whose taxonomic status still is unclear (Ronco 1990). Another pinyon, *P. discolor*, is associated with the oak woodlands of southern Arizona and New Mexico. Pinyons are commonly between 9 and 35 feet tall and 5 to 18 inches in diameter, although larger individuals can be found on wetter sites.

Juniper (*Juniperus* spp.) is the other major tree genus of these woodlands. There are four major juniper species: one-seed (*J. monosperma*); Utah (*J. osteosperma*); alligator (*J. deppeana*); and Rocky Mountain (*J. scopulorum*). In addition, redberry juniper (*J. erythrocarpa*), which is similar to one-seed juniper in appearance, occurs below the Mogollon Rim. The junipers generally are small, multistemmed trees less than 40 feet in height.

Junipers are generally more drought tolerant than pinyons, and tend to predominate on drier sites. Johnsen (1962) attributed this tolerance to the fact that juniper foliage has a small exposed surface area, sunken stomata, and a thick cuticle, all of which tend to reduce moisture losses through evapotranspiration. Barnes and Cunningham (1987) reported that one-seed juniper is able to continue photosynthesis and carbon accumulations at greater moisture stresses than associated pinyon. However, pinyon is more responsive than juniper to increased moisture. This finding would tend to support the common observation that the proportion of pinyon in the stand increases with increased elevation and moisture until it becomes the primary species at about 7,200 feet. Pinyon will have good growth and form on the better sites, and the stands will have characteristics of a true forest.

Woodland stands can have one or several species of junipers, but the distribution of junipers varies throughout the Southwest. Springfield (1976) indicated that Utah juniper predominates in parts of Arizona and northwest New Mexico, where winter moisture is greater than summer moisture. One-seed juniper is most common in areas where winters are cool and dry and where summer monsoon precipitation is more important. The distribution of alligator juniper, which is associated with the Madrean woodlands of southern Arizona and Mexico, also is related to the occurrence of summer moisture. Rocky Mountain juniper, which is less drought-tolerant than the other junipers, depends upon summer and early fall precipitation in the Southwest (Noble 1990). It generally occurs above 6,000 feet in northern New Mexico.

The average pinyon-juniper stand in northern Arizona and in New Mexico is uneven-aged (Barger and Ffolliott 1972). Pinyons account for 61% of the trees and are most common in the smaller size classes. The average stand contains 462 trees and 90 square feet of basal area per acre (Barger and Ffolliott 1972). Junipers make up slightly more than half of the basal area and 47% of the stand cubic foot volume. Schuler and Smith (1988) report that mixed stands are denser and more productive than pure stands of either pinyon or juniper. The pinyon-juniper type in Arizona averages about 698 cubic feet per acre, while juniper lands average about 375 cubic feet per acre (Conner et al. 1990).

Seed Production

Pinyon is monoecious, although dioecious trees are found when the trees are under insect attack or growing under stressed conditions (Gottfried 1987). Seed crops occur every 4 to 7 years depending upon the weather, site conditions, and insect herbivory. Crops are more frequent on the better sites. Trees can start bearing cones at 25 years, but production peaks when trees are between 75 and 100 years old. Cones require three growing seasons to mature and will contain about 20 relatively large, wingless seeds. A productive tree can produce about 20 pounds of seed, and an acre can yield about 300 pounds of seed (Ronco 1990). Mature seed release starts in mid-September and can continue for a 50-day period.

Some of the southwestern junipers are monoecious, such as Utah and alligator junipers, and some are dioecious, such as one-seed and Rocky Mountain junipers (Johnsen and Alexander 1974). Seed-bearing age varies by species and also can be affected by moisture conditions and competition (Gottfried 1989, McPherson and Wright 1987). One-seed and Rocky Mountain junipers begin bearing seed at between 10 and 20 years, while Utah juniper begins at about 33 years (Gottfried 1989). Female juniper flowers are 3- to 8-pointed scales that contain 1 to 2 ovules. The scales become fleshy and merge to form the characteristic juniper berry. The berry can contain 1 to 4 seeds depending on the species. Berries can be dry and leathery, for example, in Utah juniper, or thin and resinous, as in one-seed juniper. Trees flower in the spring and berries ripen in the fall; however, some species require two years for the berries to mature. Mature berries can stay on the tree for several years before dispersal. Redberry juniper, which is adapted to the prevalence of summer moisture, flowers in the late fall and fruits mature in the late spring (Fletcher 1985).

Seed Dispersal

Wind and gravity are not important dispersal agents for the heavy seeds or berries. Gottfried and Ronco (in preparation) found that most pinyon seed will fall directly below the canopy and that very few seeds will land in the adjacent interspace areas. Birds are considered to be the most important dispersal agents. Balda (1987) found four species of corvid birds to be responsible for caching hundreds of thousands of pinyon seeds during years with large cone crops: scrub jay (*Aphelocoma coerulescens*), pinyon jay (*Gymnorhinus cyanocephalus*), Clark's nutcracker (*Nucifraga columbiana*), and Steller's jay (*Cyanocitta stelleri*). Some of these species have special anatomical adaptations which allow them to transport large quantities of seed over considerable distances. The Steller's jay and Clark's nutcracker spend much of their time in higher elevation forests and contribute little to woodland regeneration.

Hall and Balda (1988) studied caching behavior of scrub jays, the only species to spend its entire life in the woodlands, and found that they prefer to cache seeds in the soil under pinyon trees even when other locations were available. In addition, these authors found that the birds, plus mice, will recover 92% of the caches. The surviving caches are the source of future pinyon regeneration.

Birds also are important for juniper dispersal. Townsend's solitaires (*Myadestes townsendi*) are important dispersal agents for one-seed juniper (Salomonson 1978) and Bohemian waxwings (*Bombycilla garrula*) are important for Rocky Mountain juniper (Noble 1990). In addition to birds, other wildlife species, such as coyotes (*Canis latrans*), mice, and rabbits, and livestock are considered major dispersal agents for junipers (Johnsen 1962, Noble 1990).

Germination, Establishment, and Early Growth

The environmental and physiological requirements for successful pinyon germination have not been evaluated fully. Preliminary data from an ongoing study have shown the pinyon seeds will germinate in the spring, but if conditions are not satisfactory, they may not germinate until the summer monsoon rain season.[3] Pinyon percent germination is relatively high between 83 and 96% (Gottfried and Heidmann 1986, Ronco 1990). Most juniper seeds also will germinate in the spring; however, germination can be delayed for up to two years because of embryo dormancy, the impermeable seed coat, or chemical inhibitors (Gottfried 1989, Johnsen and Alexander 1974). In general, the percent germination is low, ranging from 8 to 49% in Utah juniper and from 20 to 75% in one-seed juniper.

Although pinyon and juniper are considered shade-intolerant, most new seedlings are found in the shade of mature trees, shrubs, and slash. Seeds do germinate in the open, but establishment and survival are less certain. Shade moderates the microclimate and, therefore, should enhance survival.[3] Although pinyon seedlings generally are found in the shade, Meeuwig and Bassett (1983) indicated that the foliage is not dense enough to reduce light intensities below tolerance levels for survival. However, seedlings that survive the first year in the open appear to be larger than those that are growing in shaded micro-sites (Gottfried,[3] Harrington, 1987). Higher levels of total soil nitrogen, phosphorus, and potassium accumulate under the canopies than in interspaces (DeBano and J. M. Klopatek 1987), which may benefit seedling survival and growth.

Although several climatic factors influence germination and establishment, moisture is probably the most critical factor. Meagher (1943) found that supplemental watering did not influence percent germination but it did improve the speed of germination and survival of pinyon seedlings over a 2-year period. Rapid germination would favor a seedling by allowing it to become established prior to the summer or fall drought periods (Gottfried 1987). Meagher (1943) also determined that shade and/or watering had a similar effect on Utah and one-seed juniper germination and initial survival. One-seed juniper seeds must be buried less than an inch into the ground to germinate and the soil should be continually moist but not saturated (Johnsen 1962). Johnsen (1962) also reported that one-seed juniper seedling survival under drought is directly related to age. Competition from grasses will limit regeneration but the impact will decline once the tree roots have grown below the zone of highest grass root concentration.

Vegetative regeneration commonly has been found in alligator juniper which sprouts from stems, roots, or on the root crown after the removal or death of the main trunk. Jameson and Johnsen (1964) indicated that the ability to sprout declined as stump diameter increased. Some sprouting has been reported for one-seed juniper (Gottfried 1989).

Both pinyon and junipers exhibit slow early growth under natural conditions. New Colorado pinyon seedlings can put on between 1 and 2 inches of top growth annually (Ronco 1990). Taproot growth is more rapid, at about 7 to 11 inches during the first year (Harrington 1987). One-seed juniper can grow 1.3 inches in the first 20 months in the field (Meagher 1943). Roots for this juniper can be 9 inches long after 3 months (Johnsen 1962). Top growth of 1.6 inches in the first year has been reported for Utah juniper (Meagher 1943) and 12 inches in 8 years has been reported for Rocky Mountain juniper (Noble 1990). Actual growth rates will depend largely upon site conditions with the best growth occurring on the more moist sites (Gottfried 1987). Young junipers initially have sharp pointed leaves but the typical scale leaves begin to occur by the third year.

Seedlings growing under shrubs which can be overtopped have the best chance of survival (Meeuwig and Bassett 1983). Seedlings growing under mature trees must be released in order to accelerate growth. However, increased mortality has been observed in newly released seedlings. The reasons for this are unknown but recent research suggests that larger seedlings survive better than smaller seedlings.[3]

Growth of Older Trees

Growth of older pinyon and the junipers also is relatively slow, with best growth occurring on the more moist sites. Pinyon saplings will grow about 4 to 6 inches in height annually and mature trees will grow 2 to 4 inches annually (Ronco 1990). Pinyon will mature at ages between 75 and 200 years, and dominant trees can be over 400 years old. Little (1987) followed the growth of 19 surviving pinyon trees in New Mexico over a 47-year period. These trees were between 15 and 20 feet tall in 1938. He reported average annual height growth of 1.1 inches and average annual growth at d.b.h. of 0.06 inch, or 1 inch every 16.8 years. On better sites, pinyon can grow to 12 inches in diameter within 150 years (Ronco 1990).

Junipers generally grow slower than pinyon (Conner et al. 1990). Junipers have the ability to grow when conditions are favorable and to stop growing when conditions are unsatisfactory (Johnsen 1962). For this reason, it is difficult to age juniper trees by counting rings; there are false and missing rings in most samples. Growth rates for the four main junipers vary by species and generally decline with age. Noble (1990) reported that Rocky Mountain juniper will grow an average of 4 inches in height annually up to age 40, 1.3 inches annually from 40 to 80 years, and 0.7 inch annually from 80 to 300 years. Annual diameter growth is about 0.08 inch up to 170 years of age and 0.03 inch afterward. Utah juniper grows about 0.05 inch in diameter annually and alligator juniper about 0.05 to 0.07 inch annually (Barger and Ffolliott 1972).

Root growth varies by species. Pinyon has both lateral and vertical root systems. Lateral roots usually are found at depths of 6 to 16 inches and can extend away from the bole by a factor of two times the crown radius (Ronco 1990). Junipers have both tap and lateral roots; tap roots can be from 1.5 to 12 feet in depth, while laterals usually are concentrated in the top 36 inches of soil. One-seed juniper lateral roots are about 2.5 to 3 times as long as the tree is tall (Gottfried 1989). Roots can occupy most of the interspace areas, mining soil nutrients and moisture. Schuler and Smith (1988) suggested that the higher size/density, leaf area, and growth relations in mixed woodland stands than in pure stands can be related to differences in rooting habits and water relations between pinyon and junipers.

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[3] *Gottfried, Gerald J. Unpublished data on file at the Rocky Mountain Forest and Range Experiment Station. Flagstaff, AZ.*

Damaging Agents

A number of insects attack pinyon (Ronco 1990), including the pinyon sawfly (*Neodiprion edulicolus*), pinyon tip moth (*Dioryctria albovittella*), and the pinyon needle scale (*Matsucoccus acalyptus*). The cone moth (*Eucosma bobana*) is particularly damaging. In addition, a number of bark beetles attack pinyon; severe mortality associated with the pinyon Ips (*Ips confusus*) has been observed in areas of the Apache-Sitgreaves National Forests. The mortality has been associated with an extended drought period that weakened the tree's defenses. Pinyon dwarf mistletoe (*Arceuthobium divaricatum*) is an important parasite that can cause locally severe damage and mortality. There are also a number of additional diseases and insects that affect this species (Ronco 1990).

The junipers have their own suite of insect problems and diseases (Gottfried 1989). Some examples of insects are twig beetles (*Phloeosinus* spp.) and twig girdlers (*Stylox* spp.). Rusts (*Gymnosporangium* spp.) attack most junipers, causing witches' brooms, galls, leaf damage, and twig excrescences. True mistletoes (*Phorandendron* spp.), which are spread by birds, also are common parasites but generally do not cause heavy damage.

Fire was more of a natural factor prior to the European settlement than currently (Johnsen 1962). The present woodlands do not burn frequently, largely because overgrazing has resulted in the lack of a dense and continuous ground cover. Fire prevention policies of recent years also have played a role in reducing the frequencies of burns. Stand-replacing fires still occur but only under severe burning conditions, such as the presence of high winds, high temperatures, and drought.

Succession

Fire was the most important natural disturbance in the pinyon-juniper woodlands prior to the introduction of large herds of livestock in the nineteenth century. Johnsen (1962) indicated that grass fires maintained some sites as juniper "savannahs" because they tended to kill trees less than 3 feet tall. In recent years, there have been numerous studies of succession in old pinyon-juniper control areas (Clary et al. 1974, Rippel et al. 1983, Severson 1986b). In woodlands, successive stages usually contain the same species but in different amounts and dominance (Evans 1988). Habitat type also will affect the successional process. Arnold et al. (1964) proposed one successional sere for the Southwest, which started with the establishment of annuals and progressed to the renewed dominance of the arboreal vegetation; other pathways have also been suggested for the woodlands of southwestern Colorado and western Utah (Evans 1988). Junipers can be the first trees to invade an area, but they are often followed and replaced by pinyon. In Utah, tree dominance does not occur until 70 to 80 years following fire. Herbage yields decline as tree crown cover increases (Arnold et al. 1964). Succession has been more rapid in some cleared areas because of the presence of tree advance regeneration that survived the initial control treatment.

The Invasion of Pinyon-Juniper Woodlands

One of the most persistent questions concerning the ecology and management of the pinyon-juniper ecosystem is whether woodlands are invading true grasslands to the detriment of rangeland and soil-watershed resources. Expansion of pinyon-juniper woodlands into the oak woodlands of southeastern Arizona also has produced concern. Invasion into grasslands commonly is related to overgrazing by livestock, which reduced the density and cover of grasses and other herbaceous species. This lack of a continuous cover prevents the spread of periodic fires that killed young trees and allowed tree regeneration to become established because of reduced competition. Johnsen (1962) found that one-seed juniper seedling growth was 52% greater without competition from blue grama (*Bouteloua gracilis*) than with it, and that only the largest seedlings will survive competition. Livestock also have been implicated in the spread of juniper seeds onto and throughout the depleted rangelands.

Johnsen (1962) did not support the invasion theory. He maintained that many "invaded" grasslands contain old junipers that survived fire and that these areas should be classified as ecotonal juniper "savannahs" rather than grasslands. One-seed juniper can survive on grassland sites without the help of grazing; natural fire is the controlling factor. Older trees survive range fires because the fire moves too rapidly to generate lethal levels of heat. Johnsen stated that invaded areas are climatically woodlands and that invasion is limited to filling in the savannahs or grassland inclusions within the woodland type.

Paleobotanists feel that the invasion is controlled by climatic fluctuations and that the prehistoric fluctuations in range and density may have been greater than during historic times. Lomolino et al. (1989) indicated that the pinyon-juniper woodlands were concentrated south of the Mogollon Rim during the Pleistocene. Neilson (1987) stated that a shift in the summer monsoon to the north would have produced moister conditions favorable to woodland expansion, and that the activities of European settlers only provided site conditions which accelerated the process. Davis (1987), working with pollen records from a site in the Verde Valley of Arizona, found that the natural expansion of woodlands has accelerated since the end of the last century when livestock were introduced into the area.

MANAGEMENT

Land managers are beginning to recognize that the southwestern pinyon-juniper woodlands can produce a number of natural resources and, therefore, that these lands should be managed for multiple values. Management plans should integrate multiple resource objectives and attempt to maintain and improve the health of the ecosystem. This management philosophy is in contrast to the previous philosophies toward the woodlands that were dominated by the emphasis on single resources. Even though eradication programs were rationalized as being beneficial for streamflow augmentation and wildlife, their main goal appeared to be increased forage production for livestock. Evaluations of large pinyon-juniper control treatments in the Southwest indicated that they generally did not improve water yields or wildlife habitat, and that even forage yield increases often were not obtained or could not be sustained (Clary et al. 1974, Rippel et al. 1983, Short et al. 1977, Howard et al. 1990).

Management for several resources requires a knowledge of how various treatments affect each of the resources. The most comprehensive multiresource research involved the effects of eradication on wildlife, range, and water resources at Beaver Creek (Clary et al. 1974). However, there has been little research or management experience with multiresource management where fuelwood has been an important consideration. In fact, many of the basic ecological processes that are the basis for management and affect trees, understory species, and animal populations are unclear. The Rocky Mountain Forest and Range Experiment Station is attempting to fill this gap by conducting simultaneous research concerned with silvics and silviculture, watershed management and soil productivity, livestock and wildlife management, and woodland mensuration.[4] A current study being conducted on the Heber Ranger District of the Apache-Sitgreaves National Forests, for example, is attempting to determine the effects of several stand and slash treatments on tree growth, new and advance regeneration, forage quality and quantity, soil nutrient cycling, and small mammal populations. The stand treatments are single-tree selection, overstory removal, and vegetation cover conversion by harvesting or fire. There are other silvicultural prescriptions that should be evaluated in the future.

Managers from the USDA Forest Service, USDI Bureau of Indian Affairs, and other federal and state agencies also are attempting to develop prescriptions that sustain wood product production while benefiting livestock, wildlife, and watershed values. At present, management prescriptions and objectives vary throughout the Southwest. The potential applicability of common silvicultural prescriptions to the woodlands has been reviewed by Bassett (1987). Bassett (1987) concluded that single-tree selection and two-step shelterwood methods are the best. These methods are compatible with the dispersal patterns of heavy tree seed, provide protected microsites for regeneration, and are aesthetically acceptable. There are, however, some disadvantages, especially related to the costs associated with intensive management and potential damage to residual trees during subsequent harvests. Bassett (1987) presented a detailed discussion of the different tradeoffs that must be evaluated in preparing a prescription.

The clearcut method, except where alligator juniper is common, and the seed-tree method generally result in unsatisfactory regeneration success because of poor seed dispersal. Small clearcuts can be appropriate when dwarf mistletoe control is necessary. Any silvicultural prescription should be compatible with habitat type characteristics. Proper management for sustained production and health of the tree resources also will require growth and yield information related to site characteristics. The recent publication of volume tables for the woodland species (Chojnacky 1988, for example), has aided management efforts.

Treatments that reduce tree densities should benefit livestock and larger game species by providing additional forage while maintaining some degree of thermal and hiding cover. However, reductions of even one-third of the tree crown cover may not affect forage production (Fowler and Witte 1987). The relationships among cover, tree regeneration, and forage yields still need to be better defined. There is a need to define spatial and temporal patterns that must be created or maintained to maximize plant and animal diversity. These criteria would vary by habitat type. The current practice of creating small, dispersed openings within woodland stands has been shown to benefit elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*) (Short et al. 1977) as well as livestock. Openings create a more diverse landscape that should favor other wildlife species. Severson (1986a), for example, found an increase in small mammal populations within cleared areas. This situation also would favor various predatory birds and those that feed on insects associated with openings. Managers must also decide if previously cleared areas should be maintained or if trees should be allowed to reoccupy the sites. Springfield (1976) and Short and McCulloch (1977), respectively, presented more in-depth reviews of range management and wildlife management within the woodlands.

Slash disposal after harvesting or vegetation type conversion is another topic being debated. Slash disposal allows for easier grass seeding, movement of livestock, and reduces the fire hazard and amount of material for insect breeding activities. However, slash provides protected micro-sites for germination and establishment of trees and herbaceous vegetation, and also provides protection from herbivory. Clearing operations that involved slash burning have had a negative effect on soil nutrients, especially nitrogen and phosphorus (DeBano et al. 1987,

[4] *Gottfried, Gerald J. New perspectives and Forest Service Research for the southwestern pinyon-juniper woodlands. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. Unpublished manuscript. 31 p.*

DeBano and J. M. Klopatek 1988) and soil microorganisms (C. C. Klopatek et al. 1990). Tiedemann (1987) estimated that it would take between 428 and 856 years for an area to recover the nitrogen lost through woodland eradication and associated slash disposal. This estimate has implications for a site's sustained, long-term productivity for herbaceous species or trees. Slash also provides some erosion protection by retarding surface water movement and by serving as a place where sediment can accumulate and not be lost from the site.

The main soil and watershed management concern in the woodlands is related to accelerated erosion. Land management techniques that maintain healthy stands of vegetation on an area will retard erosion. Structures also can be used if severe problems exist. There is some discussion whether the woodlands cause accelerated erosion relative to a grass cover. However, it appears that many of the erosion channels might have begun following the period of overgrazing but prior to the closing of the tree canopy. Infiltration is relatively high under the tree canopies; however, Evans (1988) reported that there is little overall difference in infiltration rates between undisturbed and chained plots. Heede (1987) found that sediment delivery from wooded small watersheds was lower than from nonwooded areas. In addition to water-generated erosion, it appears that wind can move significant amounts of soil and nutrients under certain circumstances.

Another management concern is the protection of archeological and historical sites. As has been noted, there is a high concentration of important sites within the woodlands. Management procedures must be developed that will allow natural resource management without damaging this nonrenewable resource. Managers also should recognize that the pinyon-juniper woodlands are connected to the culture and history of many rural populations. Managers should integrate the concerns of these people into land management plans.

CONCLUSION

The southwestern pinyon-juniper woodlands cover a large area of Arizona and New Mexico. Managing these lands has evolved over the years to the current recognition of their value for a number of natural resources. Ecological information about requirements of component species and the entire ecosystem is necessary to prepare sound land management prescriptions, regardless of the mix of resources. Further research on woodland ecology and management options, which are linked to a recognition of habitat type differences, will ensure the health and productivity of this important ecosystem.

LITERATURE CITED

Arnold, Joseph F.; Jameson, Donald A.; Reid, Elbert H. 1964. The pinyon-juniper type in Arizona: effects of grazing, fire, and tree control. Prod. Res. Rep. 84. Washington, DC: U.S. Department of Agriculture. 28 p.

Balda, Russell P. 1987. Avian impacts on pinyon-juniper woodlands. In: Proceedings, Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 525-533.

Barger, Roland L.; Ffolliott, Peter F. 1972. Physical characteristics and utilization of major woodland tree species in Arizona. Res. Pap. RM-83. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 80 p.

Barnes, Fairley J.; Cunningham, G. L. 1987. Water relations and productivity in pinyon-juniper habitat types. In: Proceedings, Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 406-411.

Bassett, Richard L. 1987. Silvicultural systems for pinyon-juniper. In: Proceedings, Pinyon-juniper conference; 1986 January 13-16; Reno, NV, Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 273-278.

Chojnacky, David C. 1988. Juniper, pinyon, oak, and mesquite volume equations for Arizona. Res. Pap. INT-391. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 11 p.

Clary, Warren P.; Baker, Malchus B. Jr. ; O'Connell, Paul F.; Johnsen, Jr., Thomas N.; Campbell, Ralph E. 1974. Effects of pinyon-juniper removal on natural resource products and uses in Arizona. Res. Pap. RM-128. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 28 p.

Conner, Rodger C.; Born, J. David; Green, Alan W.; O'Brien, Renee A. 1990. Forest Resources of Arizona. Res. Bull. INT-69. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 92 p.

Davis, Owen K. 1987. Palynological evidence for historic juniper invasion in central Arizona: A late-Quaternary perspective. In: Proceedings, Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 120-124.

DeBano, Leonard F.; Klopatek, J. M. 1987. Effect of management on nutrient dynamics in southwestern pinyon juniper woodlands. In: Management of subalpine forests: Building on 50 years of research; 1987 July 6-9, Silver Creek, CO. Gen. Tech. Rep. RM-149. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 157-160.

DeBano, Leonard F.; Klopatek, Jeffrey M. 1988. Phosphorus dynamics of pinyon-juniper soils following simulated burning. Soil Science Society of America Journal. 52: 271-277.

DeBano, L. F.; Perry, H. M.; Overby, S. T. 1987. Effects of fuelwood harvesting and slash burning on biomass and nutrient relationships in a pinyon-juniper stand. In: Proceedings, Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 382-390.

Evans, Raymond A. 1988. Management of pinyon-juniper woodlands. Gen. Tech. Rep. INT-249. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 34 p.

Ffolliott, Peter F.; Rasmussen, William O.; Warfield, Thomas K.; Borland, David S. 1979. Supply, demand, and economics of fuelwood markets in selected population centers in Arizona. Arizona Land Marks 9(2). Phoenix, AZ: Arizona State Land Department. 74 p.

Fletcher, Reggie A. 1985. Differentiation of *Juniperus erythrocarpa* and *Juniperus monosperma*. Range Notes No. 3. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region. 5 p.

Fowler, John M.; Witte, Jeff M. 1987. Growth characteristics and thinning response for the pinyon-juniper type in New Mexico. In: Proceedings, Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 266-272.

Fowler, John M.; Peacock, Bruce E.; Schaber, Michael J. 1985. Pinyon-juniper woodland type in New Mexico: Asset or liability. Bull. 718. Las Cruces, NM: New Mexico State University, Agricultural Experiment Station. 67 p.

Gottfried, Gerald J. 1987. Regeneration of pinyon. In: Proceedings, Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 249-254.

Gottfried, Gerald J. 1989. Silvics of the junipers of the southwestern pinyon-juniper woodlands. In: Southwestern pinyon-juniper woodland workshop; 1989 May 8-11; Santa Fe, NM. Santa Fe, NM: Society of Range Management, New Mexico Section. 18 p.

Gottfried, Gerald J.; Heidmann, L. J. 1986. Effects of cold stratification and seed coat sterilization treatments on pinyon (*Pinus edulis*) germination. In: Proceedings, Conifer tree seed in the Inland West symposium; 1985 August 5-6; Missoula, MT. Gen. Tech. Rep. INT-203. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 38-43.

Hall, Lisa E.; Balda, Russell P. 1988. The role of scrub jays in pinyon regeneration. Final Report, Cooperative Agreement No. 28-C6-387. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 36 p.

Harrington, Michael G. 1987. Characteristics of 1-year-old natural pinyon seedlings. Res. Note RM-477. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 4 p.

Heede, Burchard H. 1987. The influence of pinyon-juniper on microtopography and sediment delivery of an Arizona watershed. In: Management of subalpine forests: Building on 50 years of research; 1987 July 6-9; Silver Creek, CO. Gen. Tech. Rep. RM-149. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 195-198.

Hibbert, Alden R. 1979. Managing vegetation to increase flow in the Colorado River Basin. Gen. Tech. Rep. RM-66. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 27 p.

Howard, V. W. Jr.; Barnitz, John A. Jr.; Southward, G. Morris. 1990. Deer use in pinyon-juniper treated by 2-way cabling. In: Managing wildlife in the Southwest: proceedings of the symposium; 1990 October 16-18; Tucson, AZ: Arizona Chapter of the Wildlife Society: 10-20.

Jameson, Donald A.; Johnsen, Thomas N. Jr. 1964. Ecology and control of alligator juniper. Weeds. 12: 140-142.

Johnsen, Thomas N. Jr. 1962. One-seed juniper invasion of northern Arizona grasslands. Ecological Monographs. 32: 187-207.

Johnsen, Thomas N.; Alexander, Robert R. 1974. *Juniperus* L. Juniper. In: Seeds of woody plants in the United States. Agric. Handb. 450. Washington, DC: U.S. Department of Agriculture, Forest Service: 460-469.

Klopatek, Carole Coe; DeBano, Leonard F.; Klopatek, Jeffrey M. 1990. Impact of fire on the microbial processes in pinyon-juniper woodlands: Management implications. In: Effects of fire management of southwestern natural resources; 1988 November 15-17, Tucson, AZ. Gen. Tech. Rep. RM-191. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 197-205.

Little, Elbert L. Jr. 1987. Pinyon trees (*Pinus edulis*) remeasured after 47 years. In: Proceedings, Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 65-68.

Lomolino, Mark V.; Brown, James H.; Davis, Russell. 1989. Island biogeography of montane forest mammals in the American Southwest. Ecology. 70: 180-194.

McLain, William H. 1988. Arizona's 1984 fuelwood harvest. Res. Bull. INT-57. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 8 p.

McPherson, Guy R.; Wright, Henry A. 1987. Factors affecting reproductive maturity of redberry juniper (*Juniperus pinchotii*). Forest Ecology and Management. 21: 191-196.

Meagher, George S. 1943. Reaction of pinon and juniper seedlings to artificial shade and supplemental watering. Journal of Forestry. 41: 480-482.

Meeuwig, Robert O.; Bassett, Richard L. 1983. Pinyon-juniper. In: Silvicultural systems for the major forest types of the United States. Agric. Handb. 445. Washington, DC: U.S. Department of Agriculture, Forest Service: 84-86.

Moir, W. H.; Carleton, J. O. 1987. Classification of pinyon-juniper (P-J) sites on the national forests in the Southwest. In: Proceedings, Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station: 216-226.

Neilson, Ronald P. 1987. On the interface between current ecological studies and the paleobotany of pinyon-juniper woodlands. In: Proceedings, Pinyon-juniper conference; 1986 January 13-16; Reno NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 93-98.

Noble, Daniel L. 1990. *Juniperus scopulorum* Sarg. Rocky Mountain juniper. In: Silvics of North America, Vol. 1. Conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 116-126.

Rippel, Paul; Pieper, Rex D.; Lymbery, Gordon A. 1983. Vegetational evaluation of pinyon-juniper cabling in south-central New Mexico. Journal of Range Management. 36: 13-15.

Ronco, Frank P. Jr. 1990. *Pinus edulis* Englm. Pinyon. In: Silvics of North America, Vol. 1. conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 32
337.

Salomonson, Michael G. 1978. Adaptations for anim
dispersal of one-seed juniper seeds. Oecologia (Berl.). 32: 333-339.

Schuler, Thomas M.; Smith, Frederick W. 1988. Effects of species mix on size/density and leaf-ar
relations in southwest pinyon/juniper woodlands
Forest Ecology and Management. 25: 211-220.

Severson, Kieth E. 1986a. Small mammals in modified pinyon-juniper woodlands, New Mexico. Journal of Range Management. 39: 31-34.

Severson, Kieth E. 1986b. Woody plant reestablishment in modified pinyon-juniper woodlands, New Mexico. Journal of Range Management. 39: 438-442.

Short, Henry L.; Evans, Wain; Boeker, Erwin L. 1977. The use of natural and modified pinyon pi
juniper woodlands by deer and elk. Journal of Wildlife Management. 41: 543-559.

Short, Henry L.; McCulloch, Clay Y. 1977. Managi
pinyon-juniper ranges for wildlife. Gen. Tech. Re
RM-47. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 10 p.

Springfield, H. W. 1976. Characteristics and manag
ment of southwestern pinyon-juniper ranges: Th
status of our knowledge. Res. Pap. RM-160. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Ran
Experiment Station. 32 p.

Tiedemann, Arthur R. 1987. Nutrient accumulatio
in pinyon-juniper ecosystems--Managing for futu
site productivity. In: Proceedings, Pinyon-junipe
conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Departme
of Agriculture, Forest Service, Intermountain Research Station: 352-359.

Ecology and Values of Gambel Oak Woodlands[1]

Warren P. Clary and Arthur R. Tiedemann[2]

Abstract.–Gambel oak (*Quercus gambelii* Nutt.) is an important component in the vegetative cover of about 3.8 million ha of the Western United States. It occurs in Merriam's transition life zone, providing watershed stability, wildlife habitat, fuelwood, and a variety of other values. Gambel oak is difficult to remove permanently because of an extensive underground system of interconnected lignotubers, rhizomes, and roots. The species has considerable economic, conservation, and esthetic values when managed in place.

DESCRIPTION

Gambel oak (*Quercus gambelii* Nutt.) belongs to the white oak section of the genus *Quercus* (fig. 1). The species has a variable growth form. It is normally a tall shrub or small tree, but it can be found as dense shrubby patches about 1 m tall, or as widely spaced trees up to 23 m tall. This morphological variation prompted early taxonomists to recognize as many as eight additional species within populations now considered Gambel oak (Harper and others 1985). The variability may have primarily an environmental source (Neilson and Wullstein 1983), a genetic source (Pendleton and others 1985), or both.

Sexual reproduction is sporadic, generally with limited success. Gambel oak flowers expand before the leaves, as do many wind-pollinated trees. Both flowers and leaves are easily killed by frost once they begin growing rapidly. On xeric sites, Gambel oak can fail to produce mature female flowers or can sustain ovule abortion (Neilson and Wullstein 1983). In the northern portion of its range (northern Utah), the species rarely reproduces from acorns. In the southern portion of its range (Arizona and New Mexico), seedlings are more common (Neilson and Wullstein 1983). In north-central Arizona, Gambel oak with diameters of 30-36 cm were the most reliable and vigorous acorn producers. Acorn production declined rapidly as trees attained diameters above 36 cm (McCulloch and others 1965).

Gambel oak regenerates asexually from adventitious buds on the lignotubers and rhizomes of existing clones (Muller 1951; Tiedemann and others 1987). These buds give rise to numerous sprouts, particu-

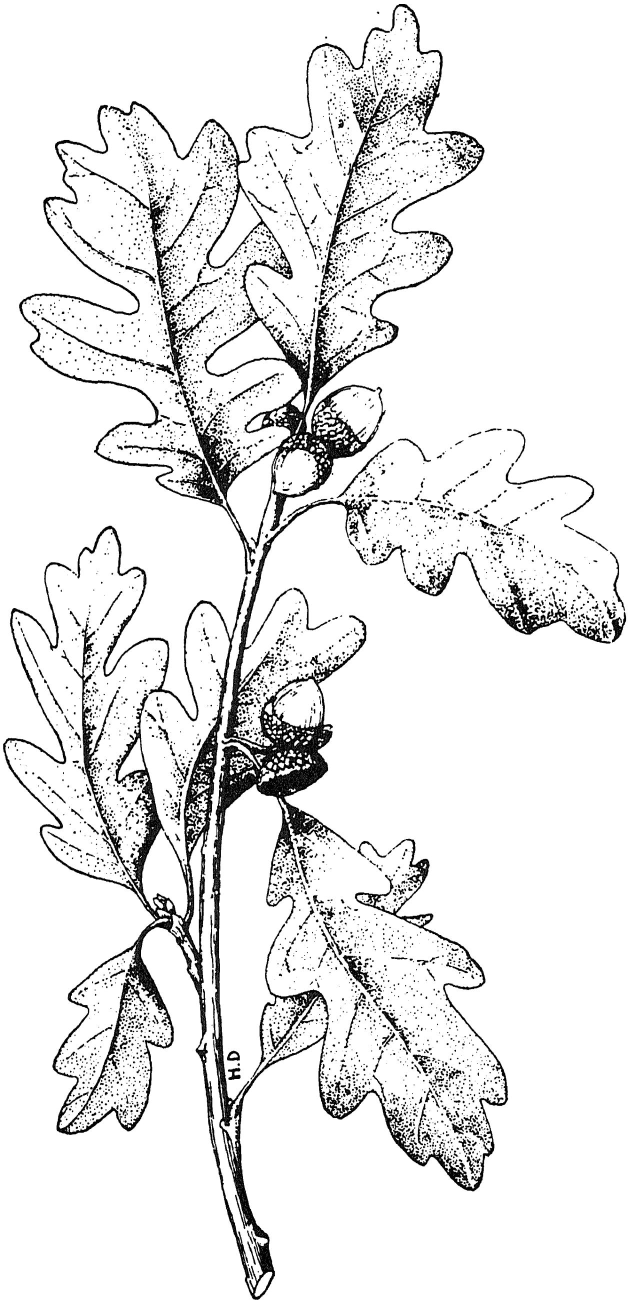

Figure 1. Foliage and fruit of Gambel oak (from U.S. Department of Agriculture, Forest Service 1937).

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larly if fire, herbicides, woodcutting, or chaining has killed the aboveground stem (Engle and others 1983).

DISTRIBUTION AND CLIMATIC RELATIONSHIPS

Gambel oak is an important component in the vegetation of about 3.8 million ha of the Western United States (Harper and others 1985). It occurs almost entirely within the Four Corner States of Arizona, Colorado, New Mexico, and Utah (fig. 2). Ecologically, Gambel oak is found within the transition life zone of Merriam (Merriam 1890), where it often is associated with ponderosa pine (*Pinus ponderosa*). Other woody associates can be bigtooth maple (*Acer grandidentatum*), white fir (*Abies concolor*), Rocky Mountain juniper (*Juniperus scopulorum*), pinyon (*Pinus edulis*), curlleaf mountain-mahogany (*Cercocarpus ledifolius*), true mountain-mahogany (*C. montanus*), serviceberry (*Amelanchier* spp.), or bitterbrush (*Purshia tridentata*) (Harper and others 1985; West 1989). The absolute elevational range is between 990 and 3,110 m (Harper and others 1985). Elevational limits are widest in the southern portion of the species' range, becoming progressively narrower toward the northern portion (Neilson and Wullstein 1983). The species often occurs in areas experiencing winter temperatures below -18 °C with mean annual temperatures of 7 to 10 °C. Precipitation within the oak zone varies between 38 and 56 cm annually. In the northern portion summers usually are dry, whereas summer precipitation is more abundant in the southern portion (Harper and others 1985; Neilson and Wullstein 1983). A lack of summer precipitation and severe spring frosts limits the species' range to the north (Neilson and Wullstein (1983).

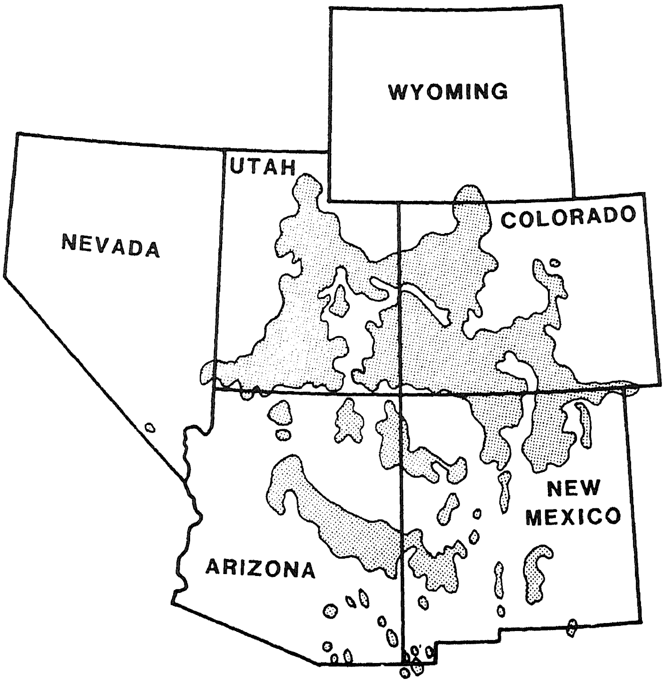

Figure 2. Distribution of Gambel oak (from Little 1971).

Little information is available on possible long-term changes in density or distribution of Gambel oak. Clones appear to expand primarily by rhizomes (Muller 1951). According to Christensen (1955), seedlings quickly develop rhizomes and form clones. The clones expand about 10 cm per year. Comparison of current and historic photographs suggests that oak clones have increased in size and number since 1900, with the most rapid increase after 1940 (Rogers 1982).

CHARACTERISTICS

Aboveground

Volume and Biomass

Information concerning the biomass or other characteristics of Gambel oak stands is limited. In west-central Colorado, Brown (1958) found one-half of the oak stems were less than 10 years old. The remainder were distributed throughout the 10- to 80-year age classes. Mature stems averaged approximately 4 m tall and 7.6 cm in stump diameter. Distribution of stem sizes in Arizona was similar. There, 60 to 75 percent of the stems were smaller than 13 cm diameter at 1.4 m in height (DBH). Basal areas varied from 3.3 to 4.3 m^2/ha, while volumes averaged 13.7 to 20.3 m^3/ha. The largest tree was 97 cm in diameter and 23.2 m tall (Barger and Ffolliott 1972). Estimates of Gambel oak volume on Colorado's southern Front Range were generally 17.5 to 24.5 m^3/ha (Betters 1986). A volume equation developed for Colorado Gambel oak stems is gross cubic foot volume = $[-0.13600 + 0.145743$ (diameter in inches at root collar squared times height in feet)$^{0.33}]^3$ (Chojnacky 1985).

We investigated the biomass characteristics of two Gambel oak populations in northcentral Utah – eight stands of shrubs and small trees and five stands of large trees (Clary and Tiedemann 1986, 1987). We sampled within individual clones. The results, therefore, do not apply directly to a landscape scale. Stem densities within the clones varied from 2,400 to 34,444 per ha, mean stand diameters varied from 3.6 to 25.6 cm, and mean stand heights varied from 2.3 to 11.8 m. Mean stand ages ranged from 36.8 to 105.0 years. The oldest tree was 142 years old.

Ovendry biomass of individual stems averaged 5.00 kg for the shrub-form and 82.5 kg for the tree-form. In both stem forms, the bole of the tree made up approximately 70 percent of the total dry weight. Total Gambel oak biomass per ha of clone averaged 63.9 to 292.1 metric tons (table 1).

Growth

Barger and Ffolliott (1972) found that annual volume growth averaged 0.24 m^3/ha, or about a 2

Table 1. – Tree biomass components per hectare of Gambel oak clone in north-central Utah.

	Stem form	
Component	Shrub and small tree	Large tree
	metric tons	
Live trees		
Foliage	2.9	5.6
Live branches	3.6	40.4
Dead branches	9.0	35.5
Boles	40.7	191.0
Total	56.2	272.5
Dead trees	7.7	19.6

percent increment. A similar annual increment was found in Utah – about 3 percent at age 60, 2 percent at age 80, and less than 2 percent after age 80 (Clary and Tiedemann 1992; Wagstaff 1984). Additional information on total growth of all oaks within Arizona woodlands can be found in Conner and others (1990).

In Utah, the two stem forms had different patterns of height growth. Height growth was rapid for both forms for the first 15 years (Clary and Tiedemann 1992). Thereafter, height growth slowed for the shrub-form stems, with little height growth after 30 years (fig. 3). Maximum height averaged 3.25 m. The tree-form stems continued growing after age 30 at slowly decreasing rates. Trees 100 years old were about 8.67 m tall (fig. 4).

The relationship between the natural logarithm of basal area and the natural logarithm of age was approximately linear in the Utah data (Clary and Tiedemann 1992). At any given age, tree-form stems had greater basal area and were accumulating basal area at a greater rate than the shrub-forms. Basal area and volume increase with age at a curvilinear rate, particularly for the tree-form stems. For example, at age 100 tree-form stems have a mean volume of 63,047 cm³, more than 18 times the 3,384 cm³ mean volume of shrub-form stems.

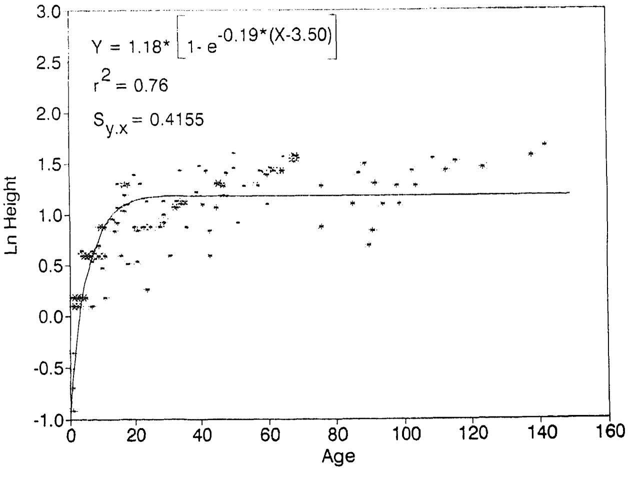

Figure 3. Height as a function of age in shrub-form Gambel oak.

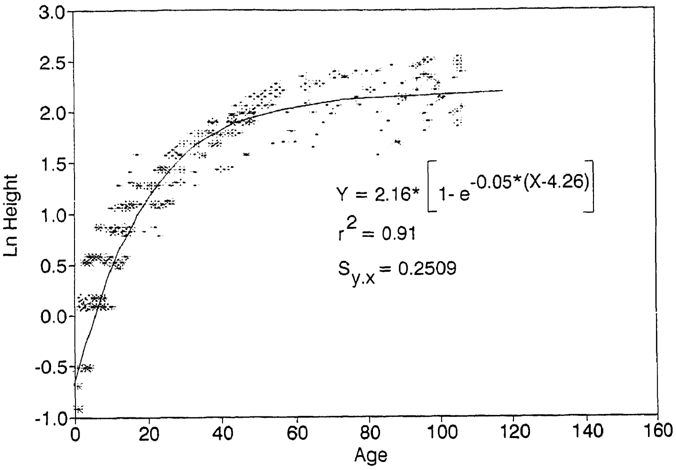

Figure 4. Height as a function of age in tree-form Gambel oak.

After natural logarithm transformation, the shrub-form and tree-form stems showed a consistent relationship between volume and basal area. A linear function fitted the full range of data for both populations (fig. 5).

Below-ground

Structure

The sprouting nature of Gambel oak has been known for many years, but the morphological basis has not been described in detail. Sprouting is concentrated at the base of the burned or cut stem, but also occurs in open areas between individual stems (Tiedemann and others 1987). Sprouting near the base of the stem suggests the presence of a lignotuber or other subterranean sprouting feature such as those described by James (1984). Sprouting between stems indicates the presence of rhizomes. Baker and Korstian (1931) found an abundance of shallow rhizomes in Gambel oak stands. Hydraulic excavation of a portion of a Gambel oak clone near Ephraim UT revealed three distinct morphological components (Tiedemann and others 1987). An enlarged stemlike

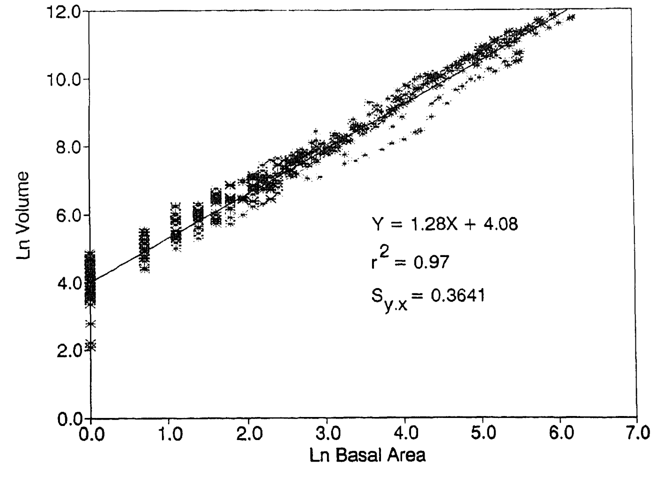

Figure 5. Volume as a function of basal area in Gambel oak.

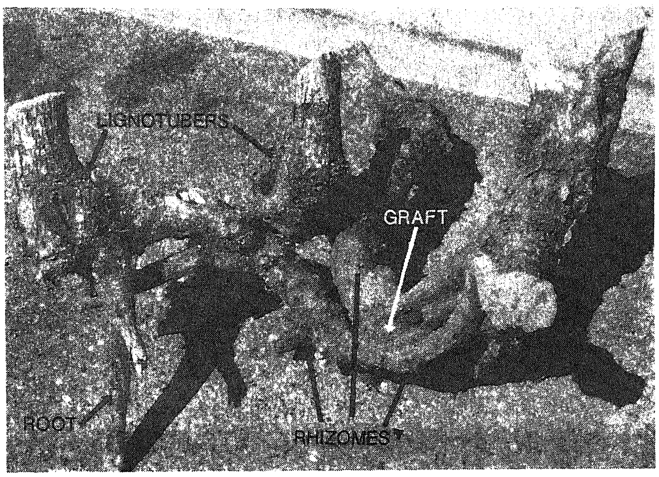

Figure 6. A portion of the underground system of Gambel oak showing stems cut at soil surface with attached subterranean lignotubers connected by rhizomes.

structure with clusters of dormant adventitious buds on its surface was at the base of each stem (fig. 6). This component fit the description of a lignotuber provided by James (1984) and Montenegro and others (1983) for shrubs of the Chilean mattoral, and by Carrodus and Blake (1970) for *Eucalyptus* in Australia. Each lignotuber was connected by a system of woody rhizomes that also had adventitious buds on the surface (fig. 7). The buds were less dense than those on the lignotuber. Lateral and vertical woody roots originating from lignotubers and rhizomes were intertwined among the woody rhizomes. Natural grafting was noted between rhizomes and between a rhizome and a root (fig. 7). Dormant adventitious buds were concentrated at a depth of 10 to 20 cm, but were found at 50 cm and below.

The lignotuber is thought to store plant nutrients (Blake and Carrodus 1970; Mullette and Bamber 1978) and maintain protected buds below the soil surface for rapid stand redevelopment after disturbance (Montenegro and others 1983; Mullette 1978). Rhizomes allow the clone to expand and are a source of sprouts in the area between lignotubers. The anatomy of lignotubers and woody rhizomes are comparable to aboveground stems, but different from roots (Tiedemann and others 1987).

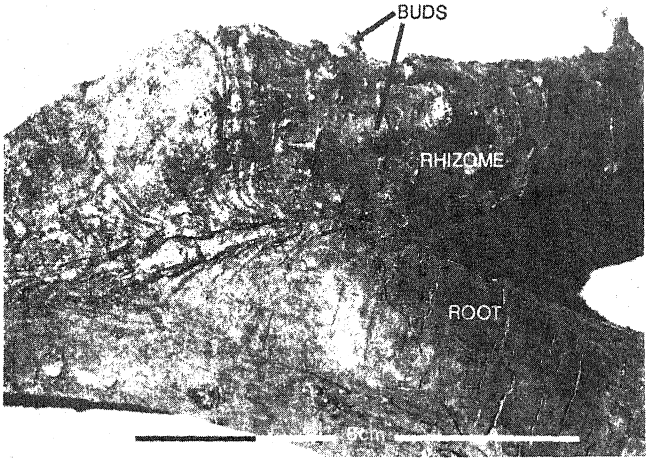

Figure 7. Graft of rhizome and root. Note buds on rhizome.

Biomass

We excavated the underground structures of Gambel oak in a 12-m^2 area in north-central Utah. The total weight was 85.2 kg or about 70,000 kg/ha of clone. Lignotubers comprised 72 percent of the belowground system. Roots and rhizomes made up 27 percent and 1 percent of the total weight, respectively.

Nutrient Content and Distribution

For sustainable productivity, managers need to understand how nutrients are distributed between a stand's biotic and abiotic components. We sampled eight Gambel oak stands for concentrations (in percent) and accumulations (kg/ha) of nitrogen, phosphorus, sulfur, calcium, magnesium, potassium, and sodium among aboveground and below-ground plant structures and the upper 30 cm of soil (Tiedemann and Clary 1985; Tiedemann and Clary in preparation). Rock and the oak's massive underground structures precluded deeper sampling. The soil contained the greatest proportion of the total capital of individual nutrients (82 to 97.9 percent). The second largest reservoir of nutrients was in the forest floor (0.7 to 9.6 percent of the total capital of individual nutrients). Most of the mineral elements accumulated in the biomass are contained by the forest floor layer (48 percent); the remainder is distributed between aboveground (25 percent) and below-ground (27 percent) components. The highest concentrations of nitrogen, phosphorus, and sulfur occurred in oak leaves, understory leaves, and the forest floor layer. The soil had the highest concentrations of calcium, magnesium, potassium, and sodium.

Removal of boles and other stand components, such as larger branches and standing dead trees, would have little impact on the total capital of an individual nutrient. Burning of slash alone would have a minor impact on the sites total nutrient capital. However, the forest floor has about 38,000 kg/ha of biomass (Clary and Tiedemann 1985). That biotic compartment has a substantial accumulation of nutrients. If boles were removed and the forest floor layer were consumed during broadcast burning of the slash, as much as 10 percent of the total site capital of nitrogen and 8 percent of the sulfur could be lost, depending upon the severity of burning (Kimmins and Feller 1976; Knight 1966; Tiedemann 1987). Losses from management actions need to be compared to replenishment rates to determine how resource productivity can best be sustained.

VALUES

Fuelwood

Gambel oak is particularly desirable as fuelwood because it produces approximately 1.4 times as much heat as ponderosa pine (Barger and Ffolliott 1972). Since it produces substantial heat and is found near several major population centers, it is attracting increasing interest as fuelwood (Betters 1986; Harper and others 1985). Retail prices reflect its high energy value: it typically sells for $10 more per ton than other wood species (Johnson and Grosjean 1980). Even if the trees have relatively small diameters, they may be valuable as fuelwood. Wagstaff (1984) reported that stems are marketable as fuelwood when the basal diameter reaches 8.9 cm. The tree-form stands we studied reached this diameter in about 50 years. Although the average shrub-form stands we studied wouldn't grow this large for a projected 230 years, a few stands would be large enough to sell as fuelwood in 90 to 100 years (Clary and Tiedemann 1992).

Wagstaff (1984) reported the amount of fuelwood that could be harvested varied greatly, but approached 1200 m^3/ha of clone on some sites. The retail value was estimated to be about \$46.31/m^3 (1983 dollars) or a maximum of about \$55,000/ha of clone if high-volume sites are completely harvested. In a separate example if we assume northern Arizona has an average marketable volume of 16 m^3/ha (Barger and Ffolliott 1972), the gross retail value of that area would be \$740/ha (1983 dollars) if all harvestable volume were removed.

Wildlife Habitat and Esthetics

Numerous wildlife species use Gambel oak to satisfy one or more habitat requirements (Reynolds and others 1970). Southwestern game species using Gambel oak include: Abert's squirrels (*Sciurus aberti*), bandtailed pigeons (*Columbia fasciata*), Merriam turkeys (*Meleagris gallopavo*), harlequin quail (*Cyrtonyx montezumae*), javelina (*Tayassu tajacu*), whitetail deer (*Odocoileus virginianus*), mule deer (*O. hemionus*), and elk (*Cervus elaphus*). The smaller species use acorns when they are available, while the ungulates use both acorns and foliage. Gambel oak foliage was the most important deer forage for summer range in north-central Arizona. Even dead leaves hanging on the trees were taken readily (Neff 1974). In winter, the nutritional value of twig tips is low (Pendleton and others 1991).

Other species using Gambel oak in the northern portion of its range include blue grouse (*Dendragapus obscurus*), ruffed grouse (*Bonasa umbellus*), magpie (*Pica pica*), and snowshoe hare (*Lepus americanus*) (Harper and others 1985). Numerous songbirds depend, at least in part, on Gambel oak (Reynolds and others 1970). Steinhoff (1978) suggested such species include: pinyon jay (*Gymnorhinus cyanocephalus*), scrub jay (*Aphelocoma coerulescens*), Steller's jay (*Cyanocitta stelleri*), green-tailed towhee (*Pipilo chlorurus*), rufous-sided towhee (*P. erythrophthalmus*), dusky flycatcher (*Empidonax oberholseri*), blue-gray gnatcatcher (*Polioptila caerulea*), black-headed grosbeak (*Pheucticus melanocephalus*), pygmy nuthatch (*Sitta pygmaea*), and plain titmouse (*Parus inornatus*).

Forest managers concerned with esthetics have high regard for Gambel oak. Many private dwellings, campgrounds, and picnic areas are located in mature oak groves. Recreationists highly value the colorful panorama of oak leaves when they turn color in the autumn (Reynolds and other 1970).

Watershed Cover and Water Use

Gambel oak stands provide excellent watershed protection. Their massive underground structures (Tiedemann and others 1987) and their heavy leaf litter deposits (Clary and Tiedemann 1986) have considerable influence on soil stability and erosion control. However, Gambel oak stands do use more soil moisture than herbaceous vegetation. In southwestern Colorado, soil moisture values increased throughout a 1.5-m profile (Marquiss 1972), when Gambel oak stands were replaced with herbaceous plants after the oak was killed by herbicides. Several studies have suggested that up to 7.6 cm of moisture would be available for runoff if Gambel oak stands were converted to herbaceous cover (Tew 1969). However, if the oak resprouts, most of the extra available moisture could be lost in 3 to 4 years (Harper and others 1985; Tew 1969).

MANAGEMENT

Attempts at Removal

Gambel oak stands provide important fall, winter, and spring habitat for deer and elk, and summer grazing for domestic cattle. However, stands can be so dense animals have a hard time getting through (Kufeld 1983). Additionally, livestock gains per ha increased about 60 percent in southwestern Colorado after oak stands were 80 percent controlled (Marquiss 1972). Fire, herbicides, and mechanical manipulation have been used to control portions of extensive oak stands to increase habitat diversity for wildlife, particularly big game, and increase forage for livestock.

Fire

Burning does not necessarily create more future herbaceous forage for livestock. Burning typically stimulates new oak sprouts. The result may be many sprouts replacing each stem killed by fire (Harper and others 1985). Some success was attained in southwestern Colorado where burning appeared to reduce the cover, density, and frequency of Gambel oak sprouts. Stands were burned twice, 2 years apart, during the midsummer when carbohydrates are depressed in 1- to 2-year-old sprouts (Harrington 1989).

When the goal is habitat diversity, removal of old stems and stimulation of new sprouts is often an objective. Total plant production may be reduced by burning, but in western Colorado, elk and cattle preferred burned sites over sprayed, chained, or control sites. Deer showed little preference among the treatments (Kufeld 1983).

Herbicides

A number of reports on the response of Gambel oak to herbicides have appeared since the mid-1960's. The earlier work focused on 2,4,5-T and 2,4,5-TP as well as picloram and ammonium sulfamate (Johnsen and others 1969). Although the aboveground stems and crowns were usually killed, vigorous sprouting followed application of almost all herbicides studied. Basal or soil applications of picloram mixtures, Bromacil, or fenuron seemed to partially control sprouts (Harper and others 1985). Tebuthiuron has controlled many oaks, but was not effective on Gambel oak on heavy-textured shale-derived soils in southwestern Colorado (Bartel and Rittenhouse 1982). On coarse-textured soils in central Utah, tebuthiuron was 99 percent effective in controlling Gambel oak, although existing understory plants were also depleted (Clary and others 1985).

Mechanical manipulation

Mechanical treatments of Gambel oak include anchor chaining, brush raking, bulldozing, roller chopping, and root plowing. In just a few years, the resulting thickets often leave ranges less desirable for livestock production than before (Engle and others 1983). Many consider two passes with anchor chains to be the best treatment to prepare oak stands for reseeding to herbaceous plants. Early observers suggested a vigorous stand of seeded grasses could minimize prolific sprouting after oak crowns were removed. This observation needs more examination (Harper and others 1985). In most cases sprouts need follow-up control by fire, herbicides, or by livestock such as goats (Davis and others 1975). Otherwise oak will often quickly regain dominance.

Management for Watershed Stability, Fuelwood, and Wildlife Habitat

Much Gambel oak research and management has focused on eliminating oak to increase herbaceous forage production and enhance conifer regeneration and growth. Forest managers have historically assumed that Gambel oak is a serious competitor with commercial tree species, such as ponderosa pine. However, this appears to be of little real concern. Biondi and Klemmedson (In press) determined that ponderosa pine's growth rate was not influenced significantly by inter-specific competition with Gambel oak. This response is likely the result of increased nutrient concentration and availability in the forest floor and soil as oak basal area increased (Klemmedson 1987, 1991; Lefevre and Klemmedson 1980), and to more favorable ratios of carbon to individual nutrients.

Elimination of Gambel oak is probably short-sighted management considering present fuelwood demands and the importance of watershed stability and wildlife habitat. Erosion potential can increase on steep slopes when stands of Gambel oak are converted to other species, especially herbaceous plants. Herbaceous roots are not likely to bind soil as well as Gambel oak's intertwined lignotubers, roots, and rhizomes. In addition, the thick litter layer beneath Gambel oak stands protects the soil surface from raindrop impact and sheet erosion (Peterson 1954). Some highly productive sites can be valuable for long-term fuelwood production. The regenerative capacity of underground lignotuber and rhizome adventitious buds should fit well into a coppice fuelwood management cycle (Tiedemann and Clary 1987). However, management for fuelwood harvest may not be practical or desirable for many Gambel oak stands. Such stands may include sites with poor growth potential, steep access, distant markets, or those having other uses of greater value.

Gambel oak seedlings are a rarity (Christensen 1955; Harper and others 1985; Neilson and Wullstein 1983), so the fate of the clone and the Gambel oak community rests on vegetative regeneration from lignotuber and rhizome meristematic buds (Tiedemann and others 1987). Distributions of buds to depths greater than 50 cm have major significance for reproduction, survival, and expansion of the clone. Fortunately, management of Gambel oak aboveground can be more flexible because of the underground regeneration capacity. But, what happens to the regenerative capacity as the clone ages? What will happen as Gambel oak is managed for fuelwood production? Other stands may not have the sprouting potential of the one we excavated. Experience with fire and fuelwood harvest indicates, however, that sprouting after disturbance is widespread throughout the range. Management should strive to assure continued vegetative reproduction of Gambel oak. If Gambel oak can no longer reproduce vegetatively, harvest could mean the demise of the stand, followed by replacement by a less valuable species from the standpoint of watershed stability and fuelwood production. Reynolds and others (1970) found that large, old Gambel oak trees in Arizona had less sprouting capability than younger stands. Further research should be conducted to resolve this important question.

In the Southwest, Gambel oak is likely to occur as an associated species within the upper pinyon-juniper and ponderosa pine zones (Barger and Ffolliott 1972). The tree-form stems typically found there are less detrimental to livestock forage production than the more shrubby stands of Colorado and Utah (Reynolds and others 1970). As a result, control or removal of Gambel oak has not been emphasized as much in the Southwest as in Colorado and Utah. In one wildlife-oriented management approach, Reynolds and others (1970) recommended: retaining most large old oaks for esthetic appeal and for cavity-dwelling wildlife; retaining high vigor trees under 38 cm diameter for mast production; and selectively removing oak stems under 20 cm diameter to stimulate sprouts for browse. Many of the removed stems would be large enough for sale as fuelwood.

SUMMARY

Gambel oak is an important vegetation component of Merriam's transition life zone in Arizona, Colorado, New Mexico, and Utah. It generally grows as a large shrub, but can become a tree on the more productive sites. The species provides shelter, forage, and mast for wildlife. Domestic animals can graze in these stands if the stem densities are not too great. In the more northern portion of the range, mature oak stands often have little forage within reach of big game. Some younger stands are nearly impenetrable to livestock or big game. Fire, herbicides, and mechanical treatments have been used to reduce Gambel oak dominance in such areas. After most treatments, Gambel oak sprouts vigorously from adventitious buds located on extensive underground structures.

Gambel oak is highly valued as fuelwood. The revenue potential of mature stands near cities and towns is substantial. Vegetative reproduction should allow a regular cycle of fuelwood harvest and regrowth on the more productive sites, especially where clones of tree-form stems or larger shrub-form stems are available. In some situations, fuelwood sales can provide a valuable tool for oak stand management. Fuelwood cutting could generate revenue while achieving various stand management goals.

In areas where Gambel oak occurs as a relatively scattered subdominant species, management is likely to emphasize wildlife habitat and esthetic values.

LITERATURE CITED

Baker, F. S.; Korstian, C. F. 1931. Suitability of brushlands in the Intermountain Region for the growth of natural or planted western yellow pine forests. Tech. Bull. 256. Washington, DC: U.S. Department of Agriculture. 82 p.

Barger, Roland L.; Ffolliott, Peter F. 1972. The physical characteristics and utilization of major woodland tree species in Arizona. Res. Pap. RM-83. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 80 p.

Bartel, Lawrence E.; Rittenhouse, Larry R. 1982. Effects of tebuthiuron on Gambel oak and associated understory vegetation. In: 35th Annual Meeting, Society for Range Management; 1982 February 7-12; Calgary, AB: 80. Abstract.

Betters, David R. 1986. Gambel oak in Colorado's Front Range. In: Ffolliott, Peter F.; Swank, Wayne T., eds. Potentials of noncommercial forest biomass for energy. Tech. Bull. 256. Tucson, AZ: University of Arizona, School of Renewable Natural Resources: 25-30.

Biondi, F.; Klemmedson, J. O. [In press]. Dendrochronological analysis of single tree interactions in mixed pine-oak stands of central Arizona, USA. Forest Ecology and Management.

Blake, T. J.; Carrodus, B. B. 1970. Studies on the lignotubers of *Eucalyptus obliqua* L'Heri. II: Endogenous inhibitor levels correlated with apical dominance. New Phytologist. 69: 1073-1079.

Brown, Harry E. 1958. Gambel oak in west-central Colorado. Ecology. 39(2): 317-327.

Carrodus, B. B.; Blake, T. J. 1970. Studies on the lignotubers of *Eucalyptus obliqua* L'Heri. I: The nature of the lignotuber. New Phytologist. 69: 1069-1072.

Chojnacky, David C. 1985. Pinyon-juniper volume equations for the central Rocky Mountain States. Res. Pap. INT-339. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 27 p.

Christensen, Earl M. 1955. Ecological notes on the mountain brush in Utah. Proceedings of Utah Academy of Science, Arts, and Letters. 32: 107-111.

Clary, Warren P.; Goodrich, Sherel; Smith, Benton M. 1985. Response of Gambel oak to tebuthiuron in central Utah. Res. Note INT-351. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 4 p.

Clary, Warren P.; Tiedemann, Arthur R. 1985. Biomass distribution in northcentral Utah gambel oak stands. In: Johnson, Kendall L., ed. Proceedings of the third Utah Shrub Ecology Workshop; 1983 August 30-31; Provo, UT. Logan, UT: Utah State University, College of Natural Resources: 9-12.

Clary, Warren P.; Tiedemann, Arthur R. 1986. Distribution of biomass within small tree and shrub form *Quercus gambelii* stands. Forest Science. 32(1): 234-242.

Clary, Warren P.; Tiedemann, Arthur R. 1987. Fuelwood potential in large-tree *Quercus gambelii* stands. Western Journal of Applied Forestry. 2(3): 87-90.

Clary, Warren P.; Tiedemann, Arthur R. 1992. Characteristics of bole volume increment in *Quercus gambelii*. Manuscript on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Forestry Sciences Laboratory, Boise, ID. 15 p.

Conner, Roger C.; Born, J. David; Green, Alan W.; O'Brien, Renee A. 1990. Forest resources of Arizona. Resour. Bull. INT-69. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 92 p.

Davis, Gary G.; Bartel, Lawrence E.; Cook, C. Wayne. 1975. Control of Gambel oak sprouts by goats. Journal of Range Management. 28(3): 216-218.

Engle, D. M.; Bonham, C. D.; Bartel, L. E. 1983. Ecological characteristics and control of Gambel oak. Journal of Range Management. 36(3): 363-365.

Harper, Kimball T.; Wagstaff, Fred J.; Kunzler, Lynn M. 1985. Biology and management of the Gambel oak vegetative type: a literature review. Gen.

Tech. Rep. INT-179. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 31 p.

Harrington, Michael G. 1989. Gambel oak root carbohydrate response to spring, summer, and fall prescribed burning. Journal of Range Management. 42(6): 504-507.

James, Susanne. 1984. Lignotubers and burls – their structure, function, and ecological significance in Mediterranean ecosystems. The Botanical Review. 50: 225-266.

Johnsen, Thomas N., Jr.; Clary, Warren P.; Ffolliott, Peter F. 1969. Gambel oak control on the Beaver Creek Pilot Watershed in Arizona. ARS 34-104. U.S. Department of Agriculture, Agricultural Research Service. 8 p.

Johnson, Carl M.; Grosjean, Mike J. 1980. Wood for heating Utah homes, an asset or liability? EL 95. Logan, UT: Cooperative Extension Service, Utah State University. 9 p.

Kimmins, J. P.; Feller, M. C. 1976. Effect of clearcutting and broadcast slashburning on nutrient budgets, streamwater chemistry, and productivity in western Canada. Oslo, Norway: 16th IUFRO World Congr Proc., Div. 1: 186-187.

Klemmedson, James O. 1987. Influence of oak in pine forests of central Arizona on selected nutrients of forest floor and soil. Soil Science Society of America Journal. 51: 1623-1628.

Klemmedson, James O. 1991. Oak influence on nutrient availability in pine forests of central Arizona. Soil Science Society of America Journal. 55: 248-253.

Knight, H. 1966. Loss of nitrogen from the forest floor by burning. Forestry Chronicle. June: 149-152.

Kufeld, Roland C. 1983. Responses of elk, mule deer, cattle, and vegetation to burning, spraying, and chaining of Gambel oak rangeland. Tech. Publ. 34. Fort Collins, CO: Colorado Division of Wildlife, Wildlife Research Section. 47 p.

Lefevre, R. E.; Klemmedson, J. O. 1980. Effect of Gambel oak on forest floor and soil of a ponderosa pine forest. Soil Society of America Journal. 44: 842-846.

Little, Elbert L., Jr. 1971. Atlas of United States trees. Vol. 1. Conifers and important hardwoods. Misc. Publ. 1146. Washington, DC: U.S. Department of Agriculture, Forest Service. 9 p. plus 254 maps.

Marquiss, R. W. 1968. Progress in chemical control of Gambel's oakbrush rangeland. Range Improvement Notes. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 13(2): 7-8.

Marquiss, Robert W. 1972. Soil moisture, forage, and beef production benefits from Gambel oak control in southwestern Colorado. Journal of Range Management. 25(2): 146-150.

McCulloch, C. Y.; Wallmo, O. C.; Ffolliott, P. F. 1965. Acorn yield of Gambel oak in northern Arizona. Res. Note RM-48. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 2 p.

Merriam, C. H. 1890. Results of a biological survey of the San Francisco Mountains Region and the desert of the Little Colorado in Arizona. U.S. Department of Agriculture. North American Fauna. 3: 1-136.

Montenegro, Gloria; Avila, Guacolda; Schatte, Peter. 1983. Presence and development of lignotubers in shrubs of the Chilean matorral. Canadian Journal of Botany. 61: 1804-1808.

Muller, Cornelius H. 1951. The significance of vegetative reproduction in *Quercus*. Madrono. 11(2): 129-137.

Mullette, K. J. 1978. Studies of the lignotubers of *Eucalyptus gummifera* (Gaertn. and Hochr.). I: The nature of the lignotuber. Australian Journal of Botany. 29: 9-13.

Mullette, K. J.; Bamber, R. K. 1978. Studies of the lignotubers of *Eucalyptus gummifera* (Gaertn. and Hochr.). III. Inheritance and chemical composition. Australian Journal of Botany. 26: 23-28.

Neff, Don J. 1974. Forage preferences of trained mule deer on the Beaver Creek watersheds. Spec. Rep. 4, Phoenix, AZ: Arizona Game and Fish Department, Research Division. 61 p.

Neilson, R. P.; Wullstein, L. H. 1983. Biogeography of two southwestern American oaks in relation to atmospheric dynamics. Journal of Biogeography. 10: 275-297.

Pendleton, Rosemary L.; Sanderson, Stewart C.; McArthur, E. Durant. 1985. Morphologic and enzymatic variability among Gambel oak clones in northcentral Utah. In: Johnson, Kendall L., ed. Proceedings of the third Utah Shrub Ecology Workshop; 1983 August 30-31; Provo, UT. Logan, UT: Utah State University, College of Natural Resources: 19-28.

Pendleton, Rosemary L.; Wagstaff, Fred J.; Welch, Bruce L. 1991. Winter deer use and nutritional value of Gambel oak forage in north-central Utah. Manuscript on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Shrub Sciences Laboratory, Provo, UT. 12 p.

Peterson, D. L. 1954. Reinventory of surface soil and plant charactistics-Morris Watershed. Salt Lake City, UT: University of Utah. 48 p. Thesis.

Reynolds, Hudson G.; Clary, Warren P.; Ffolliott, Peter F. 1970. Gambel oak for southwestern wildlife. Journal of Forestry. 68: 545-547.

Rogers, Garry F. 1982. Then and now. Salt Lake City: University of Utah Press. 152 p.

Steinhoff, Harold W. 1978. Management of Gambel oak associations for wildlife and livestock. Denver, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region; Colorado State University. 119 p. Unpublished report.

Tew, Ronald K. 1969. Converting Gambel oak sites to grass reduces soil-moisture depletion. Res. Note INT-104. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 4 p.

Tiedemann, A. R. 1987. Combustion losses of sulfur from forest foliage and litter. Forest Science. 33: 216-223.

Tiedemann, A. R.; Clary, W. P.; Barbour, R. J. 1987. Underground systems of Gambel oak (*Quercus gambelii*) in central Utah. American Journal of Botany. 74(7): 1065-1071.

Tiedemann, Arthur R.; Clary, Warren P. 1985. Nitrogen distribution in northcentral Utah Gambel oak stands. In: Johnson, Kendall L., ed. Proceedings of the third Utah Shrub Ecology Workshop; 1983 August 30-31; Provo, UT. Logan, UT: Utah State University, College of Natural Resources: 13-18.

Tiedemann, Arthur R.; Clary, Warren P. [In preparation]. Nutrient distribution in shrub- and small tree-form Gambel oak stands in central Utah. La Grande, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Forestry and Range Sciences Laboratory.

U.S. Department of Agriculture, Forest Service. 1937. Range plant handbook. Washington, DC: U.S. Department of Agriculture, Forest Service.

Wagstaff, Fred J. 1984. Economic considerations in use and management of Gambel oak for fuelwood. Gen. Tech. Rep. INT-165. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 8 p.

West, Neil E. 1989. Vegetation types of Utah. In: Johnson, Kendall L., ed. Rangeland resources of Utah. Logan, UT: Utah State University, Cooperative Extension Service: 18-56.

Fuelwood Extraction In Southeast Arizona[1]

Duane A. Bennett[2]

The demand for fuelwood in southeast Arizona during the late 1970s and early 1980s increased dramatically. Land managers on the Coronado National Forest imposed harvesting restrictions to continue a sustained yield of the fuelwood resource. This paper describes the harvesting system in place on the Sierra Vista Ranger District. Details on the area selection, marking criteria, application/permit system, and harvesting procedure are discussed.

INTRODUCTION

In the oak woodlands of southwestern United States, low precipitation and high temperatures result in slow-growing, low-density forest stands. These stands, however, are a highly utilized fuelwood resource. Over the last two decades, there has been a tremendous increase in the demand for fuelwood throughout the region and especially in southeastern Arizona. Most houses being built in this area of the State are constructed with fireplaces or wood-burning stoves as standard features (Bennett, 1990).

On the Sierra Vista Ranger District of the Coronado National Forest, which lies in Cochise and Santa Cruz counties, Arizona, fuelwood demand had increased from 900 cords sold in 1976, to 3100 cords in 1977, and to 5100 cords in 1979. After the 1979 fuelwood season, the district managers decided to place a 1500 cord limit on the amount of fuelwood to be harvested in any one year. Although little data were available on the standing volume of accessible fuelwood, it was hoped this limit would permit a sustained harvesting of this resource. Through further inventories, and increased environmental constraints, the current allowable annual cut for greenwood stands at 250 cords. Accordingly, the price of a one-cord permit increased from $2.50 in 1976, to $5.00 in 1980, to $10.00 in 1985, and to $25.00 in 1988. In 1991, the price was increased to $25.00 per half-cord. The price for a cord of oak wood sold on the local market increased from $60.00 in 1976, to $80.00 in 1979, to $130.00 in 1985, and to $210.00 in 1991 (Bennett, 1990). As a result of these price increases, wood theft is on the rise. Each time the price increased, and the temperature decreased, there would be a rash of wood theft. The remote, less visible woodlands are hardest hit by the wood poachers.

Approximately 60 percent of the fuelwood utilized in southeastern Arizona comes from federal lands, including the National Forests. The wood harvested is primarily Emory oak (*Quercus emoryi*) and alligator juniper (*Juniperus deppeana*). Nearly thirty percent of the fuelwood supplied to the market comes from privately owned ranches in the area; this wood is primarily honey mesquite (*Prosopis juliflora*). Fort Huachuca Military Reservation supplies approximately twenty percent of the fuelwood in the Greater Sierra Vista Area, while forty percent comes from National Forest lands. Approximately ten percent of the fuelwood utilized in southeastern Arizona is brought in from northern Arizona and northern New Mexico (Tolisano, 1984).

THE PERMIT SYSTEM

To harvest fuelwood on private property, nothing more than the owner's permission is required. However, if more than one-cord of mesquite is transported at one time, a permit is required by the Arizona Commission of Agriculture and Horticulture, because mesquite is a controlled species in Arizona. On most Federal or State lands, a permit is required to cut and transport wood.

When a person decides to cut fuelwood on the Sierra Vista Ranger District of the Coronado National Forest, he/she must pick up an application for a permit at the district office. Applications for downed-dead wood are generally available in August for a September harvest, and applications for green wood are available in March for an April harvest. Only one permit is authorized per household per year. The applications must be filled out and mailed to the office after a specified date. They then are accepted on a first come-first served basis.

Once issued, the permit must be in the permittee's possession at all times while fuelwood is harvested and transported. The permit is valid for the harvesting season only. Any infraction of the regulations governing the harvest will result in loss of both permit and wood, and the issuance of a violation notice.

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[1] *Paper for inclusion in the proceedings of the Oak and Associated Woodlands symposium, April 27-30, 1992, Sierra Vista, Arizona.*

[2] *Duane A. Bennett is a Recreation and Lands Forester with the Sierra Vista Ranger District, Coronado National Forest, Region 3.*

FUELWOOD HARVESTING

Fuelwood Sale Area

Fuelwood sale areas are designated at least one year in advance of the actual sale. Sale area boundaries, cutting intensities, and harvesting dates are planned in conjunction with specialists from within the Forest Service and cooperating agencies such as the Arizona Game & Fish Department, the National Park Service, and the U.S. Fish & Wildlife Service. Comments about the proposed sale are solicited from other organizations, such as The Nature Conservancy, the Wildlife Society, and Quail Unlimited, as well as the general public. Constraints such as wildlife habitats, cultural resources, access, slope, and tree species composition all affect the designation of the sale area.

Once the sale area has been delineated, trees to be removed are selected and marked with paint. Only enough trees are marked to last approximately three days to avoid high grading by the first cutters into an area. As the need arises, more fuelwood is marked. Road signs, directing cutters to the fuelwood area are placed along all travel routes likely to be used.

During the harvesting season, a forest officer is assigned to the area to insure compliance with the regulations (i.e., 6-inch stump height, 18-inch slash height), assist cutters in locating marked wood, and issue violation notices if necessary. It is required that all permits be filled out in ink prior to a load of wood leaving the fuelwood area.

After the harvesting season is over, the signs are removed and any roads created by the sale are ripped and seeded with grass.

Harvesting Procedure

Upon arrival at the sale area, the permittee locates an area where marked trees are concentrated and begins cutting. Initial size-up of each tree will indicate lean, branching, and obstacles. This can be done in a matter of seconds and is advisable to facilitate safe cutting. Due to the branching characteristics of the species harvested on the district, branchwood should be removed from the tree up to breast height first to allow safe access to the stem for the felling cuts. Once the tree is on the ground, limbing can occur. Limbs larger than two inches in diameter must be removed from the area. Next, the stemwood is removed. Stemwood is usually bucked into short (18 - 24 inch) lengths to fit into the fireplace or stove. Usable branchwood from the crown is also removed down to two inch diameter. Although this is specified in the permit, it also makes sense as these small branches serve as good kindling.

Once the half-cord of fuelwood is cut, it is loaded onto the vehicle with the bulk of the weight forward of the rear axle to facilitate better vehicle handling during transport. At this point, the permit should be filled out with the date, time, and amount of wood removed.

Fuelwood cutters tend to believe that they are saving money by cutting wood themselves rather than buying off the local market. A study by the author in the fall of 1984 showed that after spending money for a permit, safety equipment, oil and gas, and a chainsaw, the cost of a cord of wood was approximately $125.00. A breakdown of these 1984 costs is shown in Table 1. Today that cost would be approaching $200.00. Items not covered in this table include extra safety equipment, food and beverage, alternate saws, and unexpected vehicle repairs. This compares to $210.00 per cord delivered on the local market. This indicates that the savings are relatively small.

TABLE 1 – Cost of Harvesting One-Cord of Fuelwood In 1984 By A Non-Commercial Cutter

Item	Amount	Rate	Cost
Permit	1 ea.	$ 10.00	$10.00
Chainsaw	1 ea.	$200.00/10 yrs.*	$20.00
Chain	2 ea.	$ 40.00/ 3 yrs.*	$ 8.00
Saw Gas	2 gal.	$ 1.00/gal	$ 2.00
Saw Oil	6 oz.	$ 1.00/can	$ 1.00
Bar Oil	2 qts.	$ 1.00/qt.	$ 2.00
Goggles	1 pr.	$ 2.00/pr	$ 2.00
Gloves	1 pr.	$ 5.00/pr	$ 5.00
Vehicle Gas	18 gal.	$ 1.00/gal	$18.00
Vehicle Maint.	60 mi.	$ .10/mi.	$ 6.00
Chain Sharpen	2 ea.	$ 8.00/chain	$16.00
Labor	7 hrs.	$ 5.00/hr.	$35.00
			$125.00

* Total cost deferred over approximated life of item.

CONCLUSION

Intensive fuelwood harvesting has been a part of the ecosystem in southeast Arizona for the last 100 years. Only recently have shortages in the resource occurred. The demand for fuelwood has grown along with the population of the local communities. This increase has prompted new restrictions on harvesting; the price of a permit has increased many-fold while the allowable annual cut has been reduced dramatically. Fuelwood has become a precious commodity in the cold of winter. Consequently, wood poaching is on the rise throughout the area.

In the past, the public has always expected to harvest fuelwood. However, due to the slow growth patterns of native tree species, and historical harvesting practices, it is quickly becoming a luxury we may not be able to afford.

LITERATURE CITED

Bennett, Duane A. 1990. First year effects of thinning coppice on *Quercus emoryi* in southeastern Arizona. Masters Thesis. School of Renewable Natural Resources, University of Arizona, Tucson, AZ.

Tolisano, J.A. 1984. Contributions of woody biomass to energy requirements in

Arizona. Masters Thesis. School of Renewable Natural Resources, University of Arizona, Tucson, AZ.

Cultural, Recreational, and Esthetic Values of Oak Woodlands[1]

Judith G. Propper[2]

The evergreen oak woodlands of southeastern Arizona have been used by human groups for thousands of years. They hold not only commercial and wildlife values, but cultural, recreational, and aesthetic values important to contemporary society. These values need to be taken into consideration in evaluating the management needs and benefits of oak woodland environments.

INTRODUCTION

The Southwestern U.S. is a land of tremendous natural diversity and scenic beauty. Human beings have made their homes here for over 11,000 years, leaving behind many traces of their lives and cultures. Their stories are stories of a fundamental, changing, often fragile relationship with the land. This is especially true for the mountains, canyons, and grasslands of southeastern Arizona, including the evergreen oak woodlands. How human cultures were shaped by these environments and how they in turn shaped the landscape are intriguing and important areas of inquiry for archaeologists and ecologists, as well as for land managers.

The uses we make of the land today are but the most recent installments in the long continuum of human interaction with the environment (fig. 1). This paper will give a brief overview of the cultural resources and past human uses of oak woodlands in southeastern Arizona and will touch on recreational and aesthetic values as well. An awareness and appreciation of these non-commodity resources can enhance our understanding of oak woodland values and can broaden our range of management objectives and opportunities.

A LOOK AT THE PAST

In the fall of 1952, not very far from here, a flood exposed a concentration of bones in an arroyo of one of the tributaries of the San Pedro River, near the Mexican border. Excavations the following year revealed the partial remains of a mammoth. Eight Clovis points were associated with the remains (Haury, 1953). Radio-carbon dates placed the time of the mammoth kill

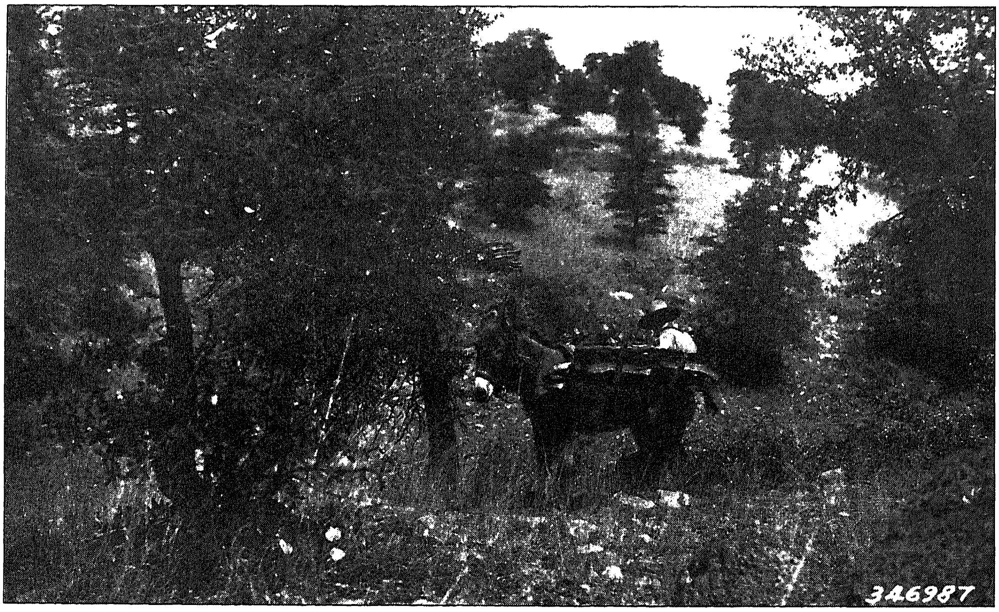

Figure 1. Oak cordwood operation in the Coronado National Forest, 1937.

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[1] Paper presented at the Oak Woodland Symposium, Sierra Vista, April 29-May 1, 1992.

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at around 11,000 years ago.

That same year in another nearby tributary, more bones were noticed. The remains of nine mammoths were later uncovered, along with thirteen Clovis points, two hearths, and an assortment of butchering tools (Haury et al. 1956). These were the first of five PalaeoIndian sites in the San Pedro Valley, making this the richest concentration of Clovis sites in the U.S. The sites were occupied during the last great era of climatic and environmental change in the Southwest, when extinct Pleistocene megafauna lived on the plains-like grasslands of southeastern Arizona.

Over the next 11,000 years, gradual climatic shifts are indicated, with a general trend toward warmer, dryer conditions, but with periods of cooler, wetter weather. Over the centuries, human groups adapted to these no doubt imperceptible changes in climate and plant and animal resources. Pleistocene megafauna gradually disappeared. Vegetation zones were displaced upward and downward. Probably more noticeable were short-term climatic fluctuations, periods of drought or higher precipitation. The landscape as we see it today is not as it appeared 11,000 years ago, or 5,000 years ago, or probably even 100 years ago. This is a crucial factor in trying to interpret the relationship between past peoples and the land.

By around 8,000 years ago, the PalaeoIndian lifeway had been replaced by the Archaic tradition, as the transition was made from Pleistocene big game hunting to seasonal use of a broader range of plant and animal resources. The Archaic way of life continued for some 6,000 years, until another transition was made, this time to increasing use of domesticated plants, probably introduced from Mexico. Associated cultural developments, including more permanent settlements, ceramic technology, and population growth were well underway by around A.D. 100. Environmental change continued to play a role in the settlement and abandonment of areas by agricultural communities over the next 1600 years.

By the late 1600s, two new cultural groups had arrived in southeastern Arizona, the Apache and the Spaniards. At that time, the San Pedro Valley was occupied by Pima-speaking Sobaipuri Indians, who practiced a combination horticultural-hunting and gathering way of life. In 1763, their numbers drastically diminished by Apache raids and European diseases, the Sobaipuri were finally evacuated by the Spanish to the Tucson area (Dobyns 1976). There, those who survived are thought to have been absorbed by the Papago, their cultural identity lost.

Conflicts with the Apache continued throughout the Spanish and Mexican periods and well into the U.S. Territorial period. It was not until the 1870s that Anglo-Hispanic settlement gained a permanent foothold in the San Pedro Valley and areas to the east. Tombstone, established in 1878, was one of several major mining districts that sprang up, with over 50 silver mines and 7 stamp mills. Ranching and farming also quickly expanded into the region.

Use of Oak Woodlands In Prehistoric and Historic Times

Looking back at these thousands of years, it is clear that the oak woodlands would have been an important ecological zone to both prehistoric and historic peoples. Acorns were an important food to indigenous people. Even one of Coronado's chroniclers noted the "sweet tasting acorns" on their journey through the San Pedro Valley (Winship 1969:91). After gathering saguaro fruit, prickly pear, grass seeds, and agave in early summer, the Apache harvested mesquite beans and acorns from the emory oak in July and August (Basso 1983:469). Acorns were used in soups and stews and were ground into meal to make bread. Acorn meal also played an important role in certain ceremonies (Hadley et al. 1991:326). In the fall, pinyon nuts and juniper berries were gathered for winter. In the late fall and winter, the woodlands would have provided white tail deer and smaller game. And as in historic times, the oak woodlands provided fuelwood and building materials. These activities no doubt had an effect on the vegetation zone, as did the prehistoric use of fire, but the overall effect was probably gentle compared to later times.

Use of the oak woodlands in the historic period was far more intensive. Minerals, when present, were totally exploited to the degree technology would allow. Fuelwood harvest was a major extractive activity. During the Tombstone mining district's heyday, 1879-1886, Bahre (1990:146-148) estimates that over 31,000 cords of mesquite and oak fuelwood were used for heating and cooking. Another 47,000 cords were used by the stamp mills. One boiler could consume an average of four cords a day. Overgrazing was also prevalent, and its effects are still being studied and debated in terms of the onset of a period of arroyo cutting that began in the late 1800s. Fire suppression in more recent times no doubt affected the composition of the woodlands.

Historic use of the oak woodlands did not deplete or destroy the oak forest due to its regenerative capabilities, but studies have documented a decrease in the number of trees, a decrease in the number of large trees, invasion of mesquite and juniper on its lower edge, and a decline in grasses, all of which are related, at least to some degree, to human factors (Bahre and Bradbury 1984; Hadley et al. 1991).

Cultural Resources in Oak Woodlands - The Rosemont Example

Evidence of prehistoric and historic land use is abundant in and near the oak woodland zone. Archaeological work in the Rosemont area, north of Sonoita, Arizona, in the early 1980s illustrates the nature of these remains (Debowski 1980; Huckel 1983). A 25 square mile area was studied, encompassing the foothills and mountain terrain at the northern end of the Santa Rita Mountains. Oak woodland communities occurred on north-facing slopes and in drainages at higher elevations. Over 600 achaeological sites were recorded during a sample survey of the area. A number of these were later tested and excavated (Fig. 2).

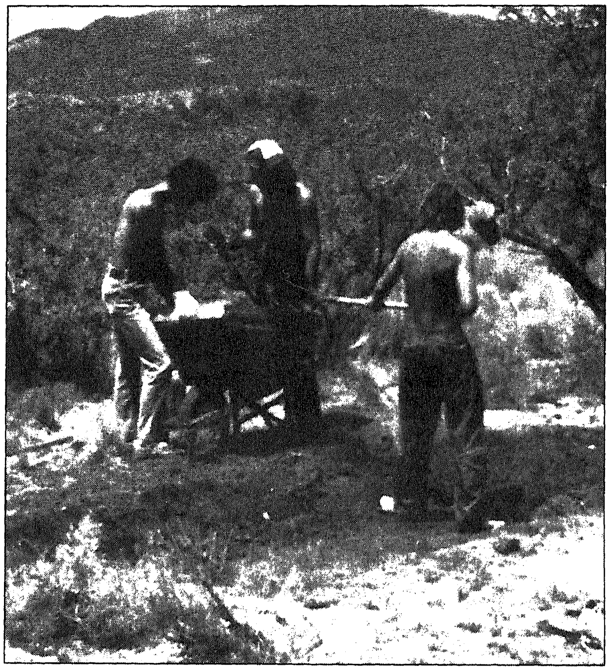

Figure 2. Archaeological investigations in the Rosemont area of the Santa Rita Mountains yielded clues to past use of oak woodlands in southeastern Arizona.

Although no evidence of PalaeoIndian remains were expected or encountered, 17 Archaic period sites were identified. Generally recognized as only a scatter of stone flakes, excavations revealed fire hearths, pits, and the outlines of several structures. Artifacts included stone spear points, knives, and scrapers, as well as grinding stones and hammer stones for processing plant foods (Huckell 1984).

Over 100 agricultural/ceramic period sites were identified and determined to be small Hohokam settlements dating from around A.D. 500 to A.D. 1200. They were located on ridges adjacent to the confluence of arroyos and larger drainages. Here check dams of piled stones slowed spring floods and ditches channeled water to planting areas in the alluvial bottoms. Again all that was visible on the surface were scatters of ceramics and stone flakes, but excavation revealed pithouses, storage pits, burials, hearths, and various activity areas (Ferg et al. 1984).

Five later Sobaipuri sites were located, recognized only as oblong rings of stones and a few surface artifacts. Remains were scarce at these probably briefly occupied sites. No Apache sites were identified. These even more ephemeral sites left few traces for archaeologists. Almost 400 sites, mostly small scatters of stone artifacts and flakes could not be identified as to cultural or time period. These probably represent brief but repeated use of the oak woodlands throughout prehistory (Tagg et al. 1984).

The Historic period in the Rosemont area is mainly represented by mining and ranching remains. Over 50 historic sites were inventoried, dating from the late 1800s to the early 1900s. These included 5 ranch complexes, 4 mining areas consisting of the mines themselves, camps, smelters, and the remains of the community of Rosemont with its hotel, post office, and other structures (Ayres 1984).

The Rosemont data illustrate the abundance of cultural resources in the oak woodlands zone. Many of these sites are fragile and can be easily destroyed. Management practices that could affect cultural resources include fuelwood harvest, range and wildlife improvements, mining operations, road construction, and other activities that disturb the surface or affect historic structures. Cultural resources need to be considered early in project planning so that sites can be identified, evaluated, and avoided or protected if appropriate. Legal requirements for cultural resources consideration are found in Section 106 of the National Historic Preservation Act and in 36 CFR 800.

In addition to scientific values related to understanding cultural development and change in the Southwest, cultural resources in the oak woodlands hold unique opportunities for interpretation and public appreciation. One example is Kentucky Camp, a mining headquarters in the foothills of the Santa Rita Mountains south of the Rosemont area. Here, volunteers are helping the Coronado National Forest document and stabilize the camp's adobe buildings. The eventual goal is to partially restore and interpret the site for Forest visitors.

A similar program is underway at Camp Rucker, near Douglas, a cavalry supply outpost during the final days of the Apache wars in the late 1800s (fig. 3). Cochise Stronghold in the Dragoon Mountains is an example of an area that has special cultural significance for living people, in this case the Chiricahua Apache.

Figure 3. Volunteers assist in recording adobe structures at Camp Rucker, a late 1800s cavalry outpost near Douglas, Arizona..

RECREATION VALUES

Because of their elevation and moderate climate, oak woodlands offer year-round recreation opportunities to enjoy special settings and points of interest (fig. 4). For the most part, however, recreationists come to the oak woodlands for hunting and for dispersed camping and picnicking. The woodlands provide a chance to "get away from it all" in an undeveloped, free, natural setting while still enjoying the use of motorized vehicles and other conveniences. As anywhere in the Forest, however, recreation takes place in settings that are the result of management actions, which may include timber harvest, range management, prescribed fire, and other activities. Management actions can therefore affect the quality of the visitor's recreation experience.

The Recreation Opportunity Spectrum (ROS) used by the Forest Service and BLM provides a systematic way to identify land areas in terms of settings which provide certain types of recreation experiences. The settings range from Primitive to Urban. ROS therefore provides a framework for evaluating management practices in terms of appropriateness for specific settings and a way to monitor impacts.

On the Coronado National Forest, the oak woodlands are characterized as primarily Semi-primitive Motorized or Roaded Natural. These settings offer experiences with a moderate probability of experiencing isolation, closeness to nature, tranquility , and self reliance. They also offer opportunities for a high degree of interaction with the environment. Proposed management actions need to take into account recreation use and possible impacts on recreation settings or opportunities to enhance those settings.

Meeting recreation demand requires forest settings that are consistent with desired experiences or expectations. It therefore helps to know what those desired experiences or expectations are. It is likely that we do not know this for the oak woodlands. We also may not know the values Forest users ascribe to these landscapes and vegetation communities. Understanding those values could help us better respond to public concerns, better plan activities to minimize conflicts, and better take advantage of opportunities to deal with those values in a positive way.

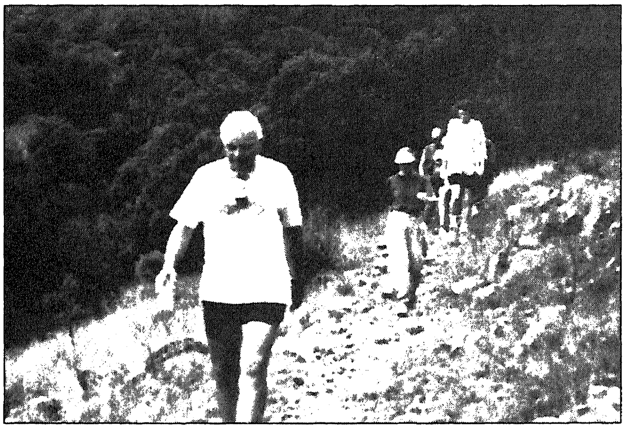

Figure 4. Hikers on the Coronado National Forest enjoy the scenery and recreation opportunities of the southeastern Arizona oak woodlands

AESTHETIC VALUES

The National Environmental Policy Act, the Forest and Rangelands Renewable Resources Planning Act, and the National Forest Management Act all identify scenic beauty as a desired product of Forest management. The oak woodlands of southeastern Arizona possess a high degree of scenic beauty, with their rolling to rugged topography, rock outcrops, frequent mountainous backdrops, and grassland mosaics at lower elevations. The Forest Service Visual Management System includes a process for establishing Visual Management Objectives for different land areas based on the distance from which the area is viewed, the visual quality concern of the viewers, and the amount of variety in the landscape. Based on these factors, a "visual quality objective" is assigned to each area: Preservation, Retention, Partial Retention, Modification, or Maximum Modification.

Most of the oak woodlands have a visual quality objective of Partial Retention under which management activities can be evident visually, but should not dominate and should blend in well. Fuel wood areas, for example, can be designed to meet this objective by using an appropriate scale for the cutting areas, designing natural-looking shapes and edges, lopping, scattering, or removing slash, and minimizing soil disturbance and compaction.

Livestock grazing can adversely affect aesthetic values by causing vegetation changes, loss of riparian habitat, and soil erosion. On the other hand, livestock can enhance visual quality when viewed as non-impacting and an integral part of the scenery or historic landscape.

All types of construction activities can result in loss of visual quality if not designed in a manner sensitive to the setting. Early consideration of visual quality objectives in project planning can help assure that aesthetic values will be preserved or enhanced.

RESEARCH NEEDS

The following areas of research could provide information and insights of value for the management of oak woodlands:

1. Impacts of prehistoric and historic land use on oak woodland environments.

2. Cultural values ascribed to oak woodlands by traditional and more recent users, and how these should be taken into account in making decisions about the woodlands' future.

3. Recreation values of oak woodlands and degree to which expectations of recreation visitors are being met.

CONCLUSIONS

Cultural, recreation, and visual resources are some of the most valued resources on National Forest lands. They provide a very personal link with the land and offer opportunities to gain a better understanding of the relationship between human beings and the rest of the natural world.

Consideration of these values in development of management objectives and project plans for oak woodlands can assure a better awareness of amenity as well as commodity resources and can contribute to a more balanced management program that will serve both the public and the woodlands well.

LITERATURE CITED

Ayres, J.E. 1984. Rosemont: The History and Archaeology of Post-1880 Sites in the Rosemont Area, Santa Rita Mountains, Arizona. Archaeological Series No. 147, Vol. 3. Arizona State Museum.

Bahre, C.J. 1990. A Legacy of Change, Historic Human Impact on Vegetation in the Arizona Borderlands. University of Arizona Press.

Bahre, C. J. and C. F. Bradbury. 1984. Impact of Historical Fuelwood Cutting on the Semidesert Woodlands of Southeastern Arizona. Office of Arid Land Studies, University of Arizona.

Basso, K.H. 1983. Western Apache. Handbook of North American Indians, Volume 10, pp. 462-488. Smithsonian Institution.

Debowski, S.S. 1980. The Anamax-Rosemont Project: An Archaeological Evaluation in the Santa Rita Mountains. Arizona State Museum.

Dobyns, H. 1976. Spanish Colonial Tucson, A Demographic History. University of Arizona Press.

Ferg, A., K.C. Rozen, W.L. Deaver, M.D. Tagg, D.A. Phillips, Jr., and D.A. Gregory. 1984. Hohokam Habitation Sites in the Northern Santa Rita Mountains. Archaeological Series No. 147, Vol. 2. Arizona State Museum.

Hadley, D., P. Warshall and D. Bufkin. 1991. Environmental Change in Aravaipa 1870-1970, An Ethnoecological Survey. Bureau of Land Management-Arizona, Cultural Resource Series, No. 7.

Haury, E.W. 1953. Artifacts with Mammoth Remains, Naco, Arizona. American Antiquity 19(1):1-14.

Haury, E.W., E.B. Sayles, and W.W. Wasley. 1959. The Lehner Mammoth Site, Southeastern Arizona. American Antiquity 25:2-30.

Huckell, B.B. 1983. The Anamax-Rosemont Testing Project. Arizona State Museum.

____________. 1984. That Archaic Occupation of the Rosemont Area, Northern Santa Rita Mountains, Southeastern Arizona. Archaeological Series, No. 147, Vol. 1. Arizona State Museum.

Tagg, M.D., R.G. Ervin, and B.B. Huckell. 1984. Miscellaneous Archaeological Studies in the Anamax-Rosemont Land Exchange Area. Archaeological Series, No. 147, Vol. 4. Arizona State Museum.

U.S. Department of Agriculture, Forest Service. 1974. National Forest Landscape Management, Volume 2.

U.S. Department of Agriculture, Forest Service. 1982. ROS Users Guide.

Winship, G.P. 1969. The Journey of Coronado, 1540-42 (Reprint, 1922 edition). AMS Press.

Utilization of Hardwoods, Fuelwood, and Special Forest Products in California, Arizona, and New Mexico[1]

Dean W. Huber[2]

Abstract.–Conifers are the major timber species in the western and southwestern United States. Harvesting and processing of these species dominate the resulting wood products industry. In contrast, hardwoods and other nontraditional species are underutilized in spite of some existing sales for fuelwood and special forest products. Systems for management of tree and shrub woodlands are being developed. The Cut-N-Reuse and Retain-N-Reuse paradigms of industrial harvesting show promise for ecosystem manipulation over the traditional Cut-N-Convert method of land management practices. A better understanding of hardwood, fuelwood, and special forest product industries could enhance rural community development and stability.

INTRODUCTION

Throughout the western United States, softwood timber species dominate the forest resource and the subsequent wood products industry. However, most hardwoods, and other species that yield special forest products, are underutilized. In the southwestern United States, hardwoods are generally of low quality and thus used for fuelwood, if harvested. Special forest products are a potpourri of non-sawtimber items such as cones, cactus, wild seeds, mushrooms, pinyon nuts, and mistletoe. Collectively, these products can represent a significant percentage of annual sales value from forest lands. More importantly, these products can be the resource for new business, employment, and economic diversity in rural communities, especially if managed in a sustained reusable manner.

LESSONS FROM FAILURES IN HARDWOODS

California has an indigenous hardwood timber resource volume estimated at 25 billion board feet in saw logs suitable for lumber recovery (Bolsinger 1988). However, no viable hardwood lumber industry has ever developed. In an effort to assess the historical reasons for failure of an industry to develop, Huber and McDonald (in press) were able to itemize 22 causes. Many of these causes are also common to poor utilization of the hardwoods and special forest products from indigenous species of the oak and pinyon-juniper woodlands of California, Arizona, and New Mexico. Some of these causes for failure include the following:

Negative attitude: Throughout the forest-zone hardwood regions of California, and the Southwest in general, a negative attitude has been evident toward utilization of anything but softwood sawtimber species. Indigenous California hardwoods are considered inferior for industrial development when compared to the vast stands of high value softwoods. Likewise, the value of indigenous hardwoods from oak woodlands in Arizona and New Mexico are considered inferior to potential benefits derived from conversion to rangeland for purposes of cattle ranching.

Sparse or intermixed stands: Unlike the dense stands of eastern hardwoods, western hardwood stands tend to be sparse or intermixed with softwoods. Thus it is difficult to selectively harvest the hardwoods in a cost-effective manner. Likewise, overall management of these stands is more complicated.

Low quality hardwoods: The quality of timber resources is directly related to the economic viability of industries dependent upon that resource. In general, western hardwoods are considered low quality based on the low yield of high-grade lumber and the high percentage of low-grade lumber yield. Low-grade lumber often does not pay its way through the processing system. Thus, western hardwood industries have had to struggle to survive.

High harvesting and processing costs: Due to the sparse or intermixed distribution of low quality western hardwoods, harvesting and processing costs are correspondingly higher than for softwoods or eastern hardwoods.

Many lumber drying problems: The process of lumber drying is complicated and complex. If not performed correctly, this can result in drying problems and degrade losses. Hardwoods with high specific gravity tend to be refractory and have a propensity for degrade due to surface check, end split, honeycomb, and collapse. This includes species such as tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehd.) in California as well as Emory oak (*Quercus emoryi* Torr.) and Gambel oak (*Q. gambelii* Nutt.) in Arizona and New Mexico.

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[1] *Paper presented at the symposium on Ecology and Management of Oak and Associated Woodlands: Perspectives in the Southwestern United States and Northern Mexico. Sierra Vista, Arizona, April 27-30, 1992.*

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Another type of drying problem may occur after processing. If lumber is not adequately dry at the time of processing, moisture loss continues to occur in the final product. Thus shrinkage continues and cracks develop between joints in furniture, flooring, and wall paneling. These cracks cause a degrade in appearance which resulted in a bad reputation to the lumber, wood products, and attendant timber species.

Fragmented industry: Due to the relatively small amount and sparse distribution of trees and stands, small sawmills and cottage industries tend to utilize hardwoods and other species that yield special forest products. This often results in a fragmented industry. Consequences of this fragmentation are lack of frequent sales to develop a base line for product price information and market trends; inability to solve common problems; and difficulty to establish the identity of industrial status.

Poor marketing practices: Marketing problems often accompany small cottage industries that are disbursed over a large geographic area. For example, there is often a lack of product standards which affects both producer and consumer; assembling adequate volumes of products makes it difficult to establish market dynamics; and product identity is difficult to develop.

Lack of technical information: Research into the physical and chemical properties of western hardwoods began after World War II. A large body of research was conducted and compiled by State forest products laboratories and several of the Forest Service research laboratories such as the U.S. Forest Products Laboratory in Madison, Wisconsin. A thorough review of this research, some of which has never been published, might disclose answers to old problems as well as new utilization opportunities (industrial chemical extracts or pharmaceutical precursors, for example). However, technical information is lacking on many subjects and for many species. Equally important is the need to repackage technical information for readability and use by industry and the general public.

These, and numerous other issues, have presented problems in establishing viable industries based on hardwoods, fuelwood, and other special forest products. It should be noted that these issues are not unique to forest based products. It should also be noted that most of these issues can be accounted for and thus resolved in an effort to establish businesses and commerce based on hardwoods, fuelwood, and special forest products.

EARLY HARDWOOD INDUSTRIES

Efforts and industries to utilize indigenous hardwood species are not new to the California, Arizona and New Mexico, referred to collectively as the Southwest in this paper. Historically, there have been several types of successful non-lumber hardwood industries in the Southwest. Origins of these industries can be traced back to 1850 and before. As a direct consequence of the Gold Rush era, and subsequent shipping and railroad development, there was a demand for heavy leather, fuelwood and charcoal, railroad ties, and mine timbers. There was, however, a limited need for hardwoods sawn into standard lumber products for housing and furniture.

To satisfy the demand for heavy leather, a source of tannin was needed. The chemical feedstock for tannin came from the bark of tanoak growing in the coastal and Sierra Nevada regions of California. Other species such as California black oak (*Q. kelloggii* Newb.) were also used, but to a lesser extent. Since there was no market for the wood, the trees were felled, the bark was stripped off, and the bole was left to rot in the forest. Numerous tanneries operated in the San Francisco Bay area as well as Santa Cruz and Monterey Counties. However, only one of these tanneries remains in operation today (Ratner 1992).

Although hardwood utilization as chemical feedstock was unique to California, the use of hardwoods for charcoal and fuelwood was common throughout the Southwest. Demand for fuelwood was high along all of the shipping lanes of transportation. Tremendous volumes of wood were cut and burned in the boilers of steam ships and railroad locomotives. This utilization of fuelwood continued until the development of petroleum based fuels. However, domestic consumption of fuelwood remains in practice as a source of heat in many homes.

Hardwoods were also ax-hewn or sawn into railroad ties and mine timbers. Although selectivity of species would eventually become part of both these industries, the early years of harvesting were almost without discretion. Thus harvesting of all species was intense within reasonable transportation distance of their intended application.

CURRENT UTILIZATION - FUELWOOD

Utilization of domestic fuelwood remains high throughout the Southwest. Both hardwood and softwood species are in demand. On the oak-woodlands and dry savanna regions with poor timber quality, hardwoods are generally sold as fuelwood. In California, Arizona and New Mexico, these hardwoods may include Gambel oak; Emory oak; California black oak; Arizona white oak (*Q. arizonica* Sarg.); gray oak (*Q. grisea* Liebm.); silverleaf oak (*Q. hypoleucoides* A. Camus); and Mexican blue oak (*Q. oblongifolia* Torr.) and mesquite (*Prosopis juliflora*

[Sw.] DC.). On limited occasions, the larger logs of California black oak, Emory, gray and silverleaf oaks may be set aside to be utilized in value-added products such as furniture.

The softwoods of the Southwest that are often used as fuelwood include oneseed juniper (*Juniperus monosperma* [Engelm.] Sarg.); alligator juniper (*J. deppeana* Steud.); Utah juniper (*J. osteosperma* [Torr.] Little); Rocky Mountain juniper (*J. scopulorum* Scarg.); and redberry juniper (*J. erythrocarpa* Cory); Coulter pine (*P. coulteri* D. Don.); Jeffrey pine (*P. Jeffreyi* Grev. & Balf.); border pinyon (*Pinus discolor* Bailey & Hawks.); Colorado pinyon (*P. edulis* Engelm.); and singleleaf pinyon (*P. monophylla* Torr. & Frem.).

The relative importance of market demand for fuelwood can be determined from the Forest Service reports on Timber Cut and Sold On National Forests Under Sales and Land Exchanges (Cut and Sold reports). For some National Forests where the volume of softwood timber sales is limited, such as the Coronado in southern Arizona, the fuelwood percentage of total product value sold can be significant (Table 1). Consequently, there is support of local business through employment; rural community stability through economic diversification; and commerce through increased turnover of dollars and taxes at the local level.

On occasion, some fuelwood cutters will set aside the larger hardwood logs for use in higher value products such as furniture stock. This has met with limited success due to the difficulty in sawing and drying the lumber. Some species tend to be very refractory and thus develop drying degrade from surface checks, honeycomb, and collapse. This characteristic is displayed by such species as tanoak, Gambel oak, Emory oak, gray oak, and silverleaf oak. To reduce lumber degrade losses in these species, they must be dried very slowly under well controlled conditions of temperature and humidity.

Table 1. Value of fuelwood sold on selected National Forests in the southwestern United States.

	Fiscal Year		
	FY 89	FY 90	FY 91
Tonto NF			
Sales value	$45,023	$46,664	$43,964
Percent of total sales value	12%	11%	27%
Coronado NF			
Sales value	$44,874	$41,900	$29,450
Percent of total sales value	89%	91%	89%
Gila NF			
Sales value	$47,453	$49,266	$43,088
Percent of total sales value	26%	39%	6%
Lincoln NF			
Sales value	$22,815	$23,812	$21,599
Percent of total sales value	7%	50%	10%
Cleveland NF			
Sales value	$12,821	$10,157	$9,645
Percent of total sales value	91%	86%	87%

CURRENT UTILIZATION – SPECIAL FOREST PRODUCTS

Enterprising entrepreneurs utilize an array of special forest products in limited quantities. Many of these forest products cannot be measured or converted into the traditional "board foot" unit of measure used for timber and saw logs. For example, pinyon nuts (fig.1.) are collected from pinyon trees, while beargrass (fig. 2.) is cut from native clump grass (*Nolina microcarpa* Wats.). To account for the special forest product type of transactions, the Forest Service uses a category called "non-convertible" sales. A broad array of these forest products (Table 2) are sold by the National Forests through small contract sales, primarily using the Forest Products Sale Permit. This report includes special forest products sold on National Forest land only, other sales occur on lands administered by the Bureau of Land Management, tribal lands, state lands and private lands. Table 3 is a listing of descriptions and uses of products in Table 2.

The itemizing of special forest products in Table 2 indicates both the type of products and their corresponding sales value from several southwestern National Forests. Also shown in Table 2 are the non-convertible sales as a percent of total product value sold. Like the fuelwood sales discussed above, the relative importance of market demand for the non-convertible products can be determined from Forest Service data found in Cut and Sold Reports. The non-convertible percentage of total value in sales can be significant for some National Forests, such as the Coronado, where the volume of softwood timber is limited. These sales also support local business

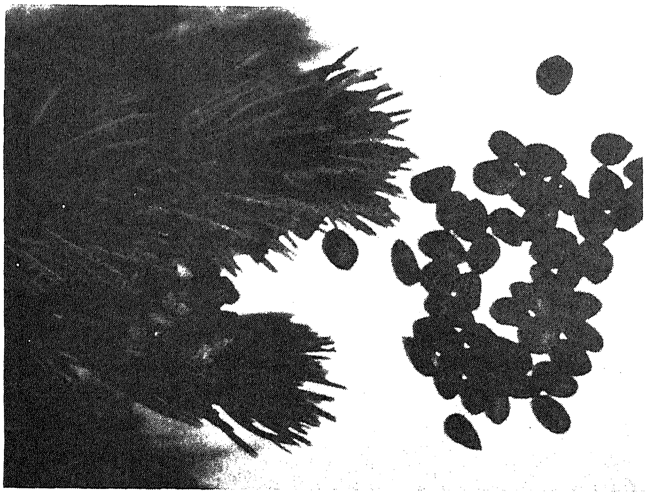

Figure 1. Pinyon nuts are harvested periodically for food.

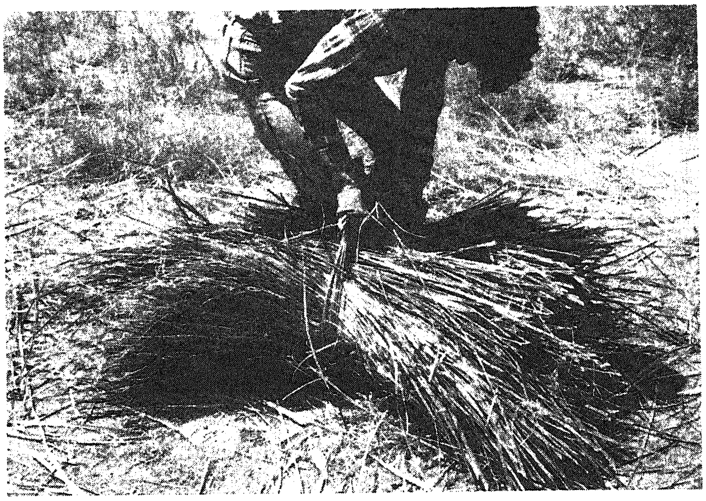

Figure 2. Beargrass is harvested for its fiber.

through employment; rural community stability through economic diversification; and commerce through increased turnover of dollars and taxes at the local level.

COMPARISON OF INDUSTRIES AND THEIR ATTENDANT HARVESTING PARADIGMS

A review of Tables 1 and 2 indicates considerable value from sales of both fuelwood and special forest products. Historical experience has shown that it is difficult to establish a major industry based on these products. Thus their potential importance to community and commerce is often ignored. However, use of hardwoods, fuelwood and special forest products often support nontraditional cottage industries which can be an essential component of economic diversity in rural communities. When comparing traditional and nontraditional industries, there are three distinctive paradigms which characterize the relationship between harvesting practices and subsequent land management practices. An overview of these industries, and their attendant harvesting paradigms, are discussed below.

Cut-N-Convert Industries

Traditional softwood and hardwood sawmill industries follow a systematic sequence of events from timber harvesting through lumber processing. These might be called a Cut-N-Convert industries because they cut the resource during harvest, followed by subsequent conversion of geometric shapes: a truncated cone (the log) is converted into a rectangular parallelepiped (the lumber). As a consequence of this harvesting method, the root stock is killed. Thus, the Cut-N-Convert industrial harvesting paradigm has a single harvest per life cycle of the biological resource.

The Cut-N-Convert industrial harvesting paradigm requires extensive reforestation practices

Table 2. Partial listing and values of special forest products from selected National Forests in the southwestern United States.[a]

	Fiscal Year		
	FY 89	FY 90	FY 91
Tonto NF			
Jojoba	$2,020	$2,075	$10,445
Cactus	150	175	176
Wildings	80	80	20
Wild seeds	40	—	25
Novelty wood	35	244	65
Drift wood	25	25	—
Mesquite beans	25	—	—
Mistletoe (true)	—	25	—
Decorative shrubs	110	95	160
Mushrooms	—	—	25
Grape vines	—	—	10
Herbs	—	—	55
Non-convertible percent of total value sold	0.7%	0.6%	6.7%
Coronado NF			
Beargrass	$1,000	$1,150	$1,395
Dry cones	5	—	25
Wildings	125	205	150
Ocotillo	25	—	—
Christmas trees	3,052	2,544	3 ,856
Decorative shrubs	55	—	—
Novelty wood	25	—	—
Non-convertible percent of total value sold	11%	9%	11%
Gila NF			
Christmas trees	$14,835	$14,995	$14,958
Seed cones	10	20	—
Beargrass	300	—	—
Wildings	566	122	538
Pinyon nuts	—	—	60
Non-convertible percent of total value sold	8%	11%	2%
Lincoln NF			
Christmas trees	$18,165	$18,595	$19,806
Wildings	1,542	2,867	2,548
Non-convertible percent of total value sold	6%	46%	10%
Cleveland NF[b]			
Wild seed	not available	200	245
Mistletoe (true)	not available	210	160
Decorative brush	not available	1210	965
Dry cones	not available	75	70
Non-convertible percent of total value sold	9%	14%	13%

[a] This information is from two different data sets: Timber Cut and Sold On National Forests Under Sales and Land Exchanges reports; and the Forest Products Sale Permit. Since not all information from the Forest Products Sale Permit was used in Table 2, the summation of indicated dollar sales cannot be used to calculate the percentage of total sale value sold. Use of the dollar values is intended to show relative differences among various special forest products. Likewise, relative differences are shown among National Forests for non-convertible percentage of total value sold.

[b] Estimated values for special forest products.

Table 3. Special Forest Products - Descriptions and uses.

Beargrass:	A wild grass cut and used for weaving and brooms.
Cactus:	Various skeletons of cholla and saguaro. Used for decorations, and crafts. Some sold as living for transplanting and landscaping.
Christmas trees:	Species include ponderosa pine, Douglas fir and pinyon pine.
Decorative shrubs and limbs:	Species include pine, Douglas fir and pinyon. Used for Christmas greens.
Decorative brush and yucca:	Species include red shank, mountain mahogany and manzanita. Used for commercial dried arrangements and scenery.
Dry cones:	Collected from ponderosa, Jeffrey, and Coulter pine. Used for decorations and crafts.
Jojoba:	A shrub whose seed is used for food, hair products, lotions and lubricating oils.
Mesquite beans:	Beans collected from mesquite. Used as source of food.
Mistletoe (true):	Mistletoe growing on oak, juniper, cottonwood. Used for Christmas decorations.
Novelty wood: Driftwood	Various dead and down ponderosa pine and juniper. Used for decoration and crafts.
Ocotillo:	From the cactus family. Used for desert landscaping.
Pinyon nuts:	Nuts from pinyon trees. Used for consumption.
Wildings:	Species vary from pinyon to juniper and some yucca. Used as transplants of trees or shrubs sold as living plants.
Wild seed:	Includes grasses, wildflowers and chapparal. Used in the commercial propagation of native species.

because the root stock has been killed as a result of harvesting. The process of planting or attaining satisfactory natural regeneration starts anew. The main issue relates to the need to reestablish the resource followed by the time required for adequate growth before another harvest. Consequently there must be a land mass and resource base large enough to sustain an industry through crop rotations of 50 to 150 years or more, depending upon species and site class. Characteristics of Cut-N-Convert industries are:

- One time harvest
- Root stock is killed as result of harvesting timber resource
- Extensive reforestation practices required
- Long period of time required for plant regrowth between harvests
- Substantial land mass and resource base required to sustain industry
- Heavy impact on land base during harvesting
- Major capital investment required

Fence posts and corral stock are Cut-N-Convert industries of a special nature. In these cases, the timber resource is once again killed in the process of harvesting. However, because the product is used in almost its native form, there may be minimal conversion in geometric shape.

Cut-N-Reuse Industries

Although trees normally reproduce through seed stock, some trees also have the capacity for asexual reproduction. For these species, another type of harvesting technique can be considered. This is the Cut-N-Reuse industrial harvesting paradigm which allows the bole to be harvested without killing the root stock. Thus a new tree begins to develop from the sprouts during the next growing season. Due to asexual reproduction, the next generation of harvestable resource is ready in less time than would be required from seed stock. Some of the Southwestern species which respond in this manner are the oaks and alligator juniper which reproduce by sprouting from the root crown and root stock (Gottfried 1992).

Since the root stock remains alive in the Cut-N-Reuse industrial harvesting paradigm, the practice of forestry and ecosystem manipulation requires less impact on the land base. This is an important advantage for the environmentally sensitive oak communities. Practices such as soil preparation and planting of seeds or seedlings are not required. However, some other aspects of intensive forestry, such as thinning and removal of excess sprouts, would be needed in order to accelerate growth.

The Cut-N-Reuse industries have a distinct advantage for harvesting products such as fiber or fuelwood. This is particularly true for products derived from species like the oaks which as otherwise slow to reproduce. This type of harvesting can support either the larger commercial industries or the smaller cottage industries. Some characteristics of the Cut-N-Reuse industries are:

- Less harvesting impact on the land
- Plants remain alive after harvesting
- Reduced cycle time between harvests
- Less land mass and resource base required to support industry
- Some aspects of intensive forestry required
- Moderate capital investment required

Retain-N-Reuse Industries

Retain-N-Reuse is a third industrial harvesting paradigm to be considered. This is similar to the Cut-N-Reuse paradigm since the root stock remains alive after harvesting. However, in contrast to the Cut-N-Reuse industries, the Retain-N-Reuse industries can harvest products annually or at least periodically. Thus, the Retain-N-Reuse paradigm may be better suited to harvesting of many of the special forest products and proper livestock grazing. For example, pinyon nuts, mistletoe, and pine cones are harvested annually without cutting the trees; beargrass and mushrooms are cut without killing the root stock; herbs, wild seeds, and prickly pears are collected annually or periodically without destroying the source plant. Some characteristics of the Retain-N-Reuse industries are:

- Low impact on land
- Annual or periodic harvest of forest products
- Plants remain alive after harvesting
- Less land mass and resource base required to support industry
- Low capital investment required

The Retain-N-Reuse industries have several additional advantages to consider. Special forest products are generally sold through small contract sales. This facilitates the opportunity to keep resource use in closer balance with resource management. Small contract sales tend to be purchased by local residents. Thus, there is a vested local interest in the land base and its management. Likewise, special forest products tend to be processed by small, cottage type industries. This contributes to the diversity of industry and thus economic stability of rural communities. In addition, ecosystem manipulation can be achieved through low-impact resource utilization. For example, cutting of beargrass removes dead material from the clump which improves cover habitat for quail; and stimulates tender regrowth which improves browsing conditions for deer (fig 3.) (Fitch 1992).

There are several requirements in the administration of resources which support Retain-N-Reuse industries. Landowners and resource agencies need to assure adequate supply of resources in order to establish a business. Although there would be higher costs in administering smaller contracts, this additional cost should be offset in better public relations with less trespass and "poaching" of desired forest products.

CONCLUSIONS

Although underutilized, there are existing sales for hardwoods, fuelwood and other special forest products from oak-woodlands and dry savanna regions in the southwestern United States. For some landowners, such as some National Forests, these sales are a significant percentage of the annual total product value sold. Better understanding of industries based on special forest products could enhance rural community stabilization and development. Part of this involves understanding the historical reasons for industrial failures. There is also the need to recognize differences between the industrial harvesting paradigms of traditional Cut-N-Convert type industries versus nontraditional Cut-N-Reuse and Retain-N-Reuse industries. The Cut-N-Reuse and Retain-N-Reuse paradigms appear to be better suited for utilization of fuelwood and other special forest products as an integral part of land management practices on oak-woodlands and dry savannas.

ACKNOWLEDGEMENT

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LITERATURE CITED

Bolsinger, Charles L. 1988. The hardwoods of California's timberlands, woodlands, and savannas. Resource Bull. PNW-RB148. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 148 p.

Fitch, James H. 1992. Silviculturist, U.S. Department of Agriculture, Forest Service, Region 3, Carson National Forest. Personal communication.

Gottfried, Gerald J. 1992. Research Forester, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. Personal communication.

Huber, Dean W.; McDonald, Philip M. (In Press) California's hardwood resource, history and reasons for lack of a sustained hardwood industry. Gen. Tech. Rep. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station.

Ratner, D. 1992. The Leather Survivor. San Francisco Chronicle, Business Extra. April 13, 1992.

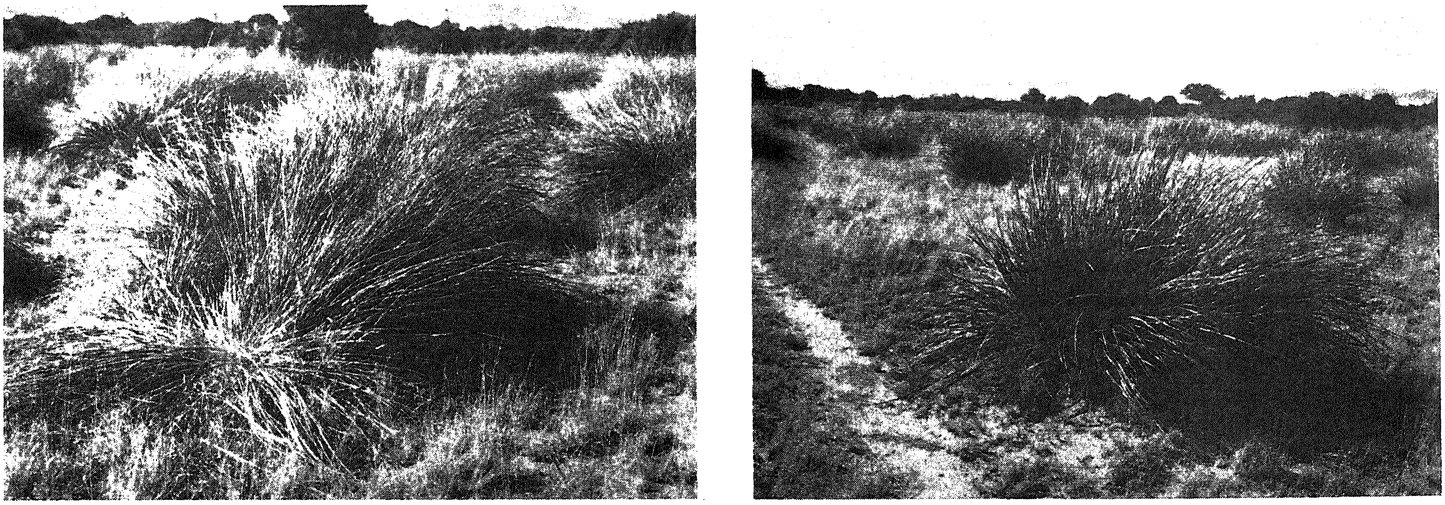

Figure 3. Ecosystem improvement by cutting of old beargrass clumps (left) compared to improved vigor and lack of dead foliage in plant (right) that were harvested 2-3 years earlier.

Livestock – Wildlife Coordination in the Encinal Oak Woodlands: Coronado National Forest[1]

Larry S. Allen[2]

Livestock Introduced to Arizona

In the mid 1500s Fray Marcos de Niza and Coronado brought the first domestic livestock to Arizona. All such animals were eaten by the Conquistadors or returned to Mexico, and they made no lasting impression on the landscape. Jesuit missionary Padre Eusebio Francisco Kino distributed cattle to mission points along the Santa Cruz River and the Arizona livestock industry was born in the late 1600s. One motive of the Padres was to concentrate the Indians around their missions, so they could educate them. Grazing was thus limited to the valleys.

Spanish and Mexican haciendas were established over the next century and a half, but hostile Apaches prevented any widespread ranching effort. At the end of the civil war, Texas was overrun with cattle because of a lack of access to northern markets during the conflict. Many of these cattle were brought to Arizona to feed the soldiers and miners. With the surrender of Apache Chief Geronimo in 1886, it became feasible to establish ranches in the mountains of southern Arizona.

Overstocking and Drought

Only about 5,000 cattle were reported to be in Arizona in 1870. However, by 1887 the governor reported that cattle grazing was a major industry and the 1891 census records one and a half million cattle. These numbers were built up during a period of above normal precipitation by ranchers who had recently come from a more humid area. They inadvertently stocked the ranges far beyond any reasonable carrying capacity, and when the inevitable drought came, the results were disastrous for the cattle and the range.

The worst drought on record occurred during 1892 and '93. In the summer of 1893 an estimated 50 to 75% of Arizona's range cattle died. Severe flooding with attendant soil loss and channel down cutting followed the drought. Factors contributing to ecological change included:

- Physical modification of channels
- Wagon road construction
- Grazing and hoof impacts
- Elimination of trees for fuel and mines
- Beaver trapping
- Placer mining
- Cultivation
- Abandonment of ancient check dams
- Confining Indians to reservations and
- Elimination of fire hunting

Most cattle were located in the river valleys and desert grasslands, and the oak woodlands escaped severe grazing impacts, due to a lack of developed water sources. No doubt the intensive grazing pressures on adjacent ranges would have forced cattle into woodland areas, but they did not stay. Evidence suggests that the oak woodlands have never been as severely impacted as adjacent valley locations.

Livestock Waters Developed

Following establishment of the National Forests in the early 1900s, ranchers and the Forest Service began to develop stock water in an attempt to distribute permitted livestock over a greater area of rangeland. This effort received a significant boost from the depression era Civilian Conservation Corps. Hundreds of waters were constructed with the help of the Corps, and the woodland became usable for yearlong cattle grazing.

Although livestock numbers had been significantly reduced, use levels still exceeded the capacity of the land through the 1930s and '40s. Habitats for resident wildlife were adversely affected by this level of grazing.

Range Management

Numbers of cattle were significantly reduced from 1930 to 1960, and adjustments continue to be made where needed. At the same time the art and science of range management has been evolving, and reductions have been accompanied with improvement in management. Quality wildlife habitat has been restored or maintained where this has occurred.

Coordination Needed

A great deal of coordination between livestock management and wildlife habitat management is required. Following are three examples:

Coues White-tailed Deer

A. No significant coordination problems are occurring at current stocking rates.
B. Hiding cover and travelways must be considered in all vegetation manipulation projects.

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[1] Poster paper presented at the Symposium on Ecology and Management of Oak and Associated Woodlands: Perspectives in the Southwestern United States and Northern Mexico. Sierra Vista, AZ. April 27-30, 1992.

[2] Rangeland Management and Ecology Staff Officer, Coronado National Forest.

C. Fence standards incorporate provisions for deer passage.
D. Livestock numbers must be regulated to prevent competition for forage.
E. Use levels and timing of grazing must be tailored to preservation of riparian habitats.

Montezuma Quail

A. Probably the most sensitive wildlife species to livestock grazing.
B. Use levels must provide adequate escape cover (about 6.5 inches stubble) from avian predators. This will limit use to approximately 45%.
C. Some small areas require heavier grazing to promote forb establishment.
D. This species is of great interest to sportsmen and birders, because of its rarity elsewhere in the U.S. The result is a great deal of public controversy over grazing practices on public lands.

Mexican Grey Wolf

A. The Mexican Wolf was extirpated from Arizona by the 1950s, to prevent predation on livestock. The subspecies is listed as endangered.
B. A recovery plan calls for reintroduction to historical habitats.
C. Arizona Game and Fish Department is currently evaluating four Arizona sites for reintroduction potential. Three of the study areas are in oak woodland vegetation.
D. Some citizens advocate removal of cattle from all potential wolf habitat to prevent future conflicts.
E. Arizona Cattlegrowers Association has endorsed the recovery effort, with certain stipulations. Some individual ranchers strongly oppose wolf release.
F. U.S. Fish and Wildlife Service is currently preparing an Environmental Impact Statement to evaluate proposed releases in Arizona and/or New Mexico.
G. Proper management of white-tailed deer habitat will provide quality habitat for wolves.

Summary

Grazing of domestic livestock is a long established land use in the oak woodlands of southern Arizona, and the ranching lifestyle this industry supports is an important part of the culture and heritage of the area. The contribution of cattle to the local economy, although somewhat overshadowed by wildlife-related recreation, is significant. Experience indicates that regulation of livestock numbers is essential to wildlife habitat management. Perhaps the level of range management is more critical.

Cattle grazing can be compatible with quality wildlife habitat in these habitats, if we identify the key wildlife habitat factors and incorporate them into range Allotment Management Plans. The Forest Services's *Integrated Resource Management* process is a useful vehicle for accomplishing this coordination.

Management and Silvicultural Practices Applied to Pine-Oak Forests in Durango, Mexico[1]

Victor Manuel Hernandez C., Francisco Javier Hernandez, and Santiago Solis Gonzales[2]

STUDY AREA

Durango state is located in the northwest region of México. It is surrounded by Chihuahua state at N and NE, Coahuila and Zacatecas at E, Jalisco and Nayarit at S, and Sinaloa at W (Inegi, 1988; Zavala, 1985). It has an extension of 11'964,800 has.

Half of Durango territory is located on the Sierra Madre Occidental with a 125 kms. width, 425 kms. length and mean altitude of 2500 º. The remaining area is located on the altiplanicie Mexicana. The lowest altitude record is registered at Tamazula, Dgo., with 250 m.º and the highest record reaches 3,300 m.º at the Huehuento Mountain.

According to the broad diversity in climatic and physiographic – conditions throughout the state, Durango is divided in four regions, each one with characteristic types of vegetation (Fig. 1). These physiographic regions are:

1. The Quebradas Region - It is characterized by its tropical type of vegetation (Deciduous tropical forest, and semideciduous tropical forest). It is located on the W side of the Sierra Madre Occidental, in a latitude range from 27 to 500 º; with warm and subhumid climate and a summer rainy season. And the annual mean precipitation is 1250 m.m. in this region (Zavala, Z. 1982, González, S. 1985).
2. The Mountains or Central Region - It involves the highest elevations of the Sierra Madre Occidental, and it is mainly covered by coniferous forest (pure pine forest, mixed pine-oak forest, and grassland-shrubs forest). The mean altitude is 2600 º; even though there are some mountains higher than 3000 m.º. It presents a temperate-cold climate with a very intensive rainy season in the summer.

   The annual mean precipitation varies from 500 to 1200 m.m., according to different areas. There are many forest species growing throughout this region; however, the most important genera in this area are: Pinus, Quercus, Cupressus, Abies, -pseudotsuga, - Juniperus, and Arbutus (González, S. 1985, Zavala, Z. 1982 and Rzendowski, J. 1981).
3. Valleys Region - It involves great plains that form extensive valleys along the E side of the Sierra Madre Occidental. The most important types of vegetation growing in this area are grassland-oak-Juniperus forest and grassland-shrubs forest. The more common genera in these areas are: Quercus, Juniperus, Pinus, Arctostaphylos, Arctos, Populus, Salix, Acacia, Prosopis, Echinocactus, Coriphanta, Yucca, and Boutelovua, Aristidia, Eurphybia. The mean altitude for the Valleys Region. The annual mean precipitation varies from 700 mm to 400 mm and the raining season takes place during the summer season.
4. The Semiarid Region - It is located at the East of Durango state. It involves different types of desert vegetation and the main genera are: Acacia, Cactus, Agave, Bursera, Mimosa, Larrea, Parthenium, Yucca, Celtis, Dasylirion, Fouquieria, Forestieria. It is formed by long prairies with an altitude from 1100 to 2100 m.º. The climate is warm and dry and a mean temperature about 23 C. The annual mean precipitation ranges from 150 to 500 mm and the raining season occurs in the summer. It has a dry season during seven to nine months.

THE OAK FOREST

The oak forest are characteristic stands dominated by the *Quercus* Genus. In Durango state, this type of forest is located not only on the Mountain of Central Region mixed with pine species, but it also forms a narrow transition zone between the pine oak, forest and the Tropical Forest at the west side of the Sierra Madre Occidental. There are other oak species on the transition zone at the East side of the Sierra Madre; it is mixed with Juniperus, Arctostaphylos, Arbutus, and Pinyon pine.

In Durango state, the oak forest grows on a temperate-cold climate with a intensive raining season occurring in summer. It is mixed with Pinus Genus, forming mixed pine-oak forest at the Mountains Region. There are small areas with a temperature and semi-dry climate at the East of the Mountain Region where oak species are growing mixed with some forest species such as *Arbutus chiapensis*, *A. xalapensis*, *Juniperus monosperma*, *Arctostaphylos pungens*, *Pinus cembroides* (Pinyon-pine) and *Pinus engelmannii* and some grass land species as *Boutelovua* sp; *Aristida*, etc. There are also a few oak species on the Quebrada Region growing mixed with

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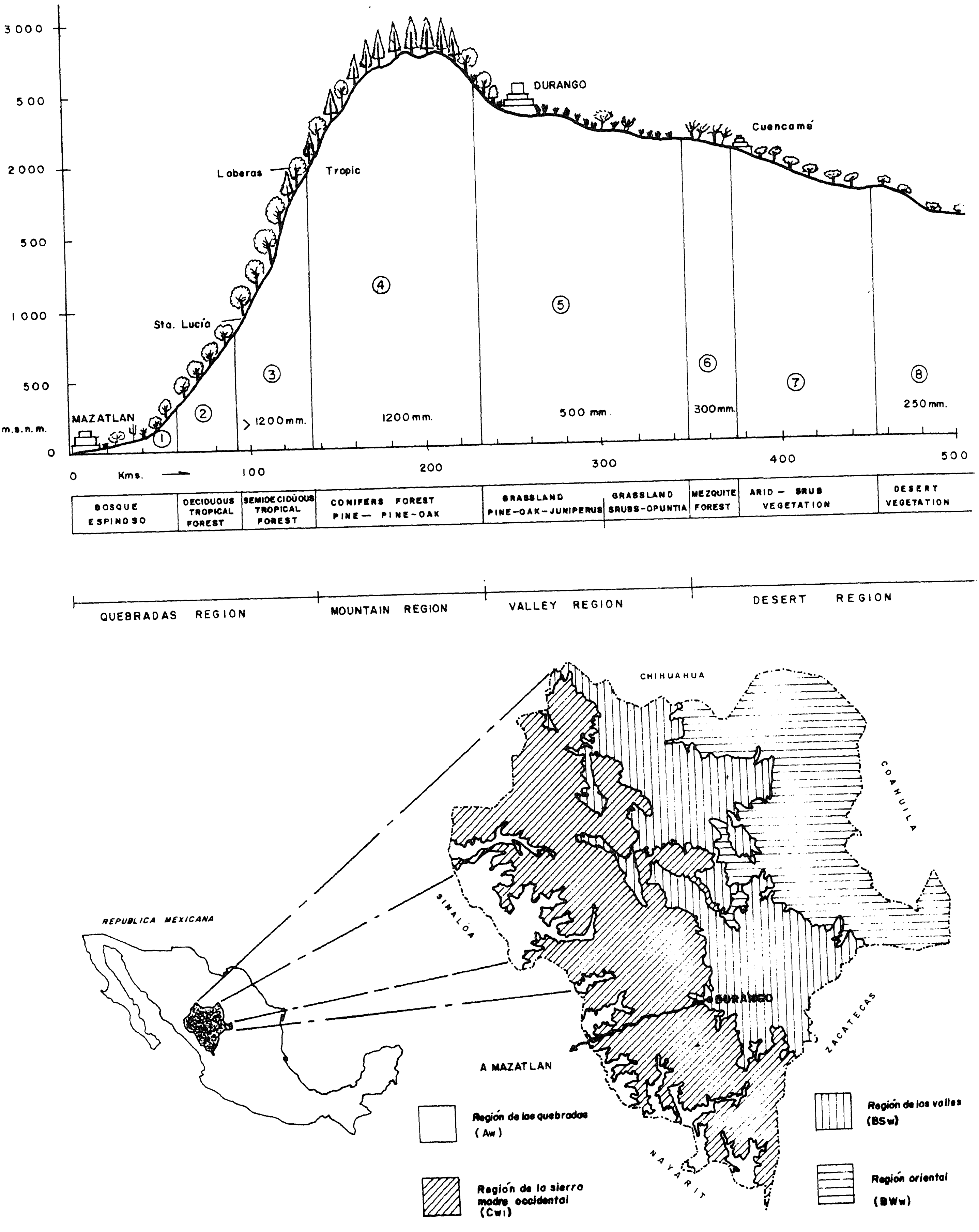
3000
500
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m.s.n.m.
0
MAZATLAN
Sta. Lucía
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DURANGO
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> 1200mm.
1200mm.
500 mm
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0 Kms.
100
200
300
400
500
BOSQUE ESPINOSO
DECIDUOUS TROPICAL FOREST
SEMIDECIDÚOUS TROPICAL FOREST
CONIFERS FOREST PINE— PINE-OAK
GRASSLAND PINE-OAK-JUNIPERUS
GRASSLAND SRUBS-OPUNTIA
MEZQUITE FOREST
ARID — SRUB VEGETATION
DESERT VEGETATION
QUEBRADAS REGION
MOUNTAIN REGION
VALLEY REGION
DESERT REGION
REPUBLICA MEXICANA
CHIHUAHUA
COAHUILA
SINALOA
DURANGO
ZACATECAS
NAYARIT
A MAZATLAN
Región de los quebradas (Aw)
Región de la sierra madre occidental (Cwi)
Región de los valles (BSw)
Región oriental (BWw)

Figure 1.

tropical species within a warm and humid climate (A) Cw. (Rzendowski, J. 1981).

According to the altitude, the Quercus Genus grows on a range of 600 to 2400 m.º on the Quebradas Region and 2000 to 2400 m.º in the middle part of Durango state.

Quercus emoryi, *Q. virens*, *Q. macrophylla*, *Q. arizonica*, *Q. intrinseca*, *Q. crassifolia*, *Q. hartwegii*, and *Q. cordifolia*, are deciduous species growing as a tree or as a small size shrubs.

At the Quebradas Region and small area in the Mountain Region, the main oak specie is *Quercus macrophylla*, mixed with tropical species as *Acacia pennatula*, *Ipomea arborences*, *Bursera* spp, and some conifers like *Pinus michoacana*, *P. oocapa*, *P. lumholtzii*, *P. tenuifola*, *P. douglasiana*, and *Pinus leiophylla*.

There are other types of forest stand (grassland-oak-Juniperus forest) on the transition zone and more dominant species are: *Quercus cordofolia*. *Q. emoryi*, *Q. chihuahuensis*, and *Q. macrophylla* mixed with *Juniperus monosperma*, *Pinus cembroides*, *P. chihuahuana*, *P. lumholtzii*, *P. engelmanii*. This type of forest is located on Valley Region forming a transition zone with the mountain region.

In the Mountain Region, within the pine-oak forest, the more common *Quercus* species are: *Quercus arizonica*, *Q. durifola*, *Q. sideroxila*, *Q. rugosa*, *Q. laxa*, *Q. omissa*, *Q. nigra*, *Q. obtusata*, *Q. resinosa*, *Q. castanea* growing mixed with *Pinus duranguensis*, *P. cooperii*, *P. herrerai*, *P. ayacahuite*, *P. teocote*, *Arbutus xalapensis*, *A. chapensis*, *Alnus* spp., *Curnus* spp., *prunus* spp., *Abies duranguensis*, *Picea chihuhuana*, *Cupresus arizonica* and *Pseudotsuga* spp.

SILVICULTURE AND MANAGEMENT PRACTICES OF PINE-OAK FORESTS

The silvicultural treatments applied to pine-oak forest are focused to conifers (pine sp). And selection thinnings and regeneration cuttings are applied to mixed pine-oak stands based on age, density and stand conditions.

Ecological restrictions are considered to protect soil, wildlife and natural resources associated to oak woodlands.

At the present time, girdling of oak trees is a common management practice to establish natural pine regeneration and protect the soil (Fig. 2). However, the results of this practice is not well documented.

The management practices applied to grassland-shrub oak forests are detrimental to natural vegetation. Since cattle overgrazing and fuelwood consumption for domestic use are conveying to soil erosion and low quality shrub oak forest.

CONCLUSIONS

According to the scarce studies conducted on oak woodlands, there is an urgent need of basic studies on the Biology, Ecology and management practices of Mexican oak species, as well as the effects of silvicultural practices such as girdling and harvesting operations on the Ecology of pine-oak Forests in Durango.

LITERATURE CITED

Bejar, M.G. 1982. Aserrío de la madera de Encino. Bol Técnica No. 62 IMF - SARH; MEX. 33 pp.

Gonzalez, S. 1985. La Vegetación de Durango. Cuaderno de Investigación Tecnológica. V.1, No. 1 CIIDIR-DGO 114 pp.

Herrera, R.J.A. et al. 1980. Durabilidad Natural de la Madera de Catorce Especies Forestales Mexicanas. Boletín Técnico 67 INF-SARH; MEX. 21 pp.

Inegi 1988. Atlas Ejidal del Estado de Durango. Encuesta Nacional Agropecuaria Ejidal, 1988.

Marmolejo, G.J. 1987. Estudio sobre la Condición de un Bosque de Encino (Quercus Affinis Scheid) en Nuevo León. Reporte Científico No. 7 Fac. de Silvicultura, U.A.N.L., MEX.

Quiñones, O.J. 1984. Potencialidad y Utilización de los Encinos en el Norte del País. En Rev. Ciencia Forestal Vol. 9 Nov-Dic. 84 INF-SARH, MEX. 3-10 pp.

Rzendowski, J. 1981. La Vegetación de México. Ed. LIMUSA, MEX. 431 pp.

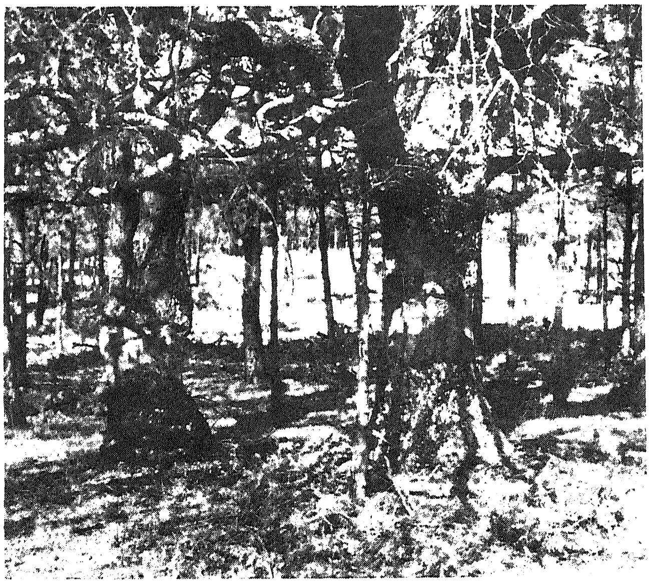

Figure 2. Silvicultural practices applied to pine-oak forest in Durango, Mexico where oak trees are girdled to promote natural pine regeneration.

Valdez, T.V. and Aguilar, M.L. 1983. El genero Quercus en las Unidades Fisionómico-Floristicas del Municipio de Santiago, N.L.-México. Bol Técnico 67 INF-SARH; MEX. 21 pp.

Zamora, S.C. 1987. Contribución al Estudio Ecológico de los Pinos en el Estado de Chiapas. Bol Técnico 56; INF-SARH; MEX. 32 pp.

Zavala, Z.R. et al., 1982. Diagnóstico de la Industria del Aserrío del Estado de Durango. Bol. Técnico No. 87 INF-SARH; México, D.F. 86 pp.

Zavala, CH. F. 1990. Los Encinos Mexicanos: Un Recurso Desaprovechado. En Ciencia y Desarrollo Vol. XVI No. 95 (Nov-Dic-90); 43-51 pp.

Ecology and Management of Californian Oak Woodlands[1]

J. W. Bartolome and R. B. Standiford[2]

California's hardwood rangelands, dominated by oaks, cover approximately 10 million acres. These rangelands have been significantly altered by human activities including burning, clearing, cultivation, livestock grazing, and alien plant introductions. In 1986 the University of California and the California Department of Forestry and Fire Protection initiated a well-funded 10-year program of research and education addressing problems with oak regeneration, wildlife habitat protection, urbanization, effective management strategies, and monitoring. This successful program offers some useful lessons for the development of comprehensive natural resource protection initiatives.

INTRODUCTION

California's oak woodlands, largely privately owned, cover approximately 10 million acres of the State (Ewing et al. 1988). Concern over the future of woodland resources led to the development of the Integrated Hardwood Range Management Program (IHRMP), which was funded in 1986. This program, coordinated among the University of California (UC), the California Department of Forestry and Fire Protection (CDF), and California Department of Fish and Game (CF&G) was designed to address five major goals: 1) improvement of oak regeneration, 2) maintenance of wildlife habitat diversity, 3) mitigation of unsound conversions of hardwood rangelands, 4) development of alternative range management strategies, and 5) monitor the status, condition, and use of hardwood rangelands (Schmidt 1988). The program has addressed these goals through a combination of basic and applied research and education.

This paper briefly reviews the ecology of oak woodlands, describes the IHRMP, and summarizes progress towards applying research to resource management.

ECOLOGY OF OAK-DOMINATED RANGELAND

Oaks dominate many ecosystems in the northern hemisphere and are particularly important in Mediterranean-type environments (Bartolome 1989). In California, oak woodlands and savannas occupy about 10 million acres of hardwood rangeland (Ewing et al. 1988). Oak-dominated cover types were divided into 7 series by Allen et al. (1991) according to dominant species. Four species dominate savannas and woodlands; the most extensive area is dominated by Quercus douglasii (blue oak), with others dominated by Q. agrifolia (coast live oak), Q. lobata (valley oak), and Q. wislizenii (interior live oak). Quercus kelloggii is primarily associated with mixed conifer forest and Q. dumosa (scrub oak) is a chaparral species. In southern California Quercus engelmanii (Engelman oak) forms mixed stands with Q. agrifolia (Griffin 1977).

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[1] Paper presented at Symposium on Ecology and Management of Oak and Associated woodlands: perspectives in the southwestern United States and Northern Mexico, Sierra Vista AZ, April 27-30, 1992

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The understory of the savannas and woodlands can be described as an extension of the adjacent open grassland under the trees (Heady 1977, Griffin 1977). Tree cover affects both species composition and productivity in the understory. In general, as rainfall increases and as canopy cover increases, the canopy suppresses production compared to open grassland (McClaran and Bartolome 1989). In areas with annual precipitation less than 50 cm, production under the canopy may exceed open grassland in winter and spring (Frost and McDougald 1989).

California's oak savannas and woodlands have formed a center for human activity for millennia. The earliest inhabitants used acorns as a major food source and likely periodically burned the landscape (Bartolome 1989). Settlement by people of European origin further altered the system by bringing in livestock, alien plants, and cultivation. Under heavy livestock grazing beginning in the late 1700's and with introduction of Mediterranean annuals, the native perennial grass understory was largely destroyed (Heady et al. 1991). Clearing of oak savanna for cultivation resulted in extensive losses, especially of Quercus lobata, which occupied fertile bottomland soils. The oak woodlands furnished abundant fuelwood, much of it used in the mining industry, and with some wood going to California's late 19th century charcoal industry.

The present woodlands and savannas variably reflect human impacts. Liveoak types have been extensively manipulated for fuelwood and cleared to improve forage production for livestock. The extensive blue oak type was also cleared for forage enhancement and fuelwood. A major concern with oak savanna and woodland resources is lack of adequate regeneration to maintain existing stands (Bartolome et al. 1988). Traditional land uses like livestock grazing are under increasing pressure from urbanization and agricultural conversions, and environmental groups blame livestock for the lack of oak recruitment (Ewing et al. 1988).

THE INTEGRATED HARDWOOD RANGE MANAGEMENT PROGRAM

The IHRMP, proposed by UC, was funded in response to perceived ecologically-based management problems faced by the CDF and CF&G. One important incident was a planned extensive fuelwood harvesting operation in mule deer winter range. Another stimulus for action was a growing public concern about the lack of adequate oak regeneration. The IHRMP focused on ways to deal with these biologically-based problems, but has evolved towards increasing emphasis on education and policy-oriented research (Schmidt 1988, Schmidt and Tinnin 1989, Standiford and Kerner 1990, McCreary et al. 1991).

The IHRMP was designed and funded as a 10-year program. The initial budget authorized annual expenditures of $650,000 by UC, augmented by a one-year $350,000 appropriation to the CDF for funding short-term applied research. The UC funds were divided between a $250,000 program for competitive research grants and $400,000 for hiring five regional extension specialists based throughout the State. As originally developed, the California Department of Fish and Game was a major partner in the IHRMP. However CF&G participation has been disappointing, with few personnel and funds assigned to the program.

The program has several unusual characteristics. First, the IHRMP is adequately funded. Second, the program was designed from the onset to attack a few well-defined problems with oak resources. Third, responsibility was clearly defined for three aspects of the program: CDF for short-term applied research, UC Regional Extension specialists for education and outreach, and UC Competitive research grants for longer-term basic research. Fourth, the program has an independent policy advisory committee to provide guidance for the program.

After 5 years, the program was judged successful in accomplishing original research goals (Standiford and Kerner 1990), with 65 different research projects funded

(McCreary et al. 1991). Goals and a summary of progress are listed below. The listed goals, taken from Standiford and Kerner (1990) differ slightly in wording, but not direction, from the original IHRMP goals.

Goal 1: Regeneration and restoration of hardwood rangelands. During the first 5 years of the program 57 percent of the funding from UC was applied to regeneration research (McCreary et al. 1991). Previous surveys had found that at least three important hardwood range species were not regenerating adequately (Quercus douglasii, Q. lobata, and Q. engelmanii). Even where seedlings grew, saplings rarely developed. The program's research has led to practical methods for artificial regeneration of all species, a better understanding of natural regeneration (but not as much progress towards practical applications), and effective education of the public (Standiford and Kerner 1990).

Goal 2: Maintenance of Wildlife Habitat Diversity. More wildlife species use hardwood habitats than any other vegetation type in California, with at least 331 vertebrates known to breed on hardwood range. Fifteen percent of UC research dollars went to wildlife research, which primarily established the importance of hardwoods to dependent species (McCreary et al. 1991). Recent projects have shifted research from traditional wildlife/habitat studies to methods for effectively assessing the impact of urbanization on wildlife. Much of this research has been summarized in a forthcoming publication, Wildlife among the Oaks.

Goal 3: Show consequences of hardwood range conversion. When the IHRMP began, it first emphasized ecological factors and traditional resource management problems. Issues related to land-use planning, environmental planning, and urbanization have now been shown to be of significance and are receiving more attention. The majority of funding for this work has come from CDF, with UC contributions through the regional specialists and an aggressive educational program for planners and the public. Considerable progress has been demonstrated in this area as shown by an extensive independent evaluation of the ability of the program to reach the target audiences (McCreary et al. 1991).

Goal 4: Develop alternative management strategies. Because hardwood range is primarily privately owned and traditionally used for livestock production, the program sought to develop alternative management practices which could improve the economic status of landowners, leading to stability in ownership and resource conservation. IHRMP workshops for landowners have successfully illustrated ways to combine economic success with resource conservation although no startling breakthroughs in management have been identified (McCreary et al. 1991).

Goal 5: Monitoring the status of hardwood rangelands. A major objective for the program is to improve the database for planning and decision-making. This has been a major undertaking funded by CDF, with progress but little application thus far. One interesting result of the monitoring program is that the extent of firewood cutting and range conversion was much less than previously believed (Standiford and Kerner 1990).

CONCLUSIONS

The IHRMP has spent considerable amounts of money, about $500,000 annually on basic and applied research, and an additional $400,000/year on regional extension specialists. Has this program been worth it? When the program started, the public, scientists, landowners, and regulators were at odds over the health of hardwood rangeland resources. The public was demanding new regulations to protect vanishing oak resources. Landowners were fearful of new and costly restrictions on their activities. Scientists claimed more research was needed. Regulators foresaw problems with conflicting goals for resource use and protection.

The IHRMP is best described as a

program of research (develop more reliable knowledge) and education (extend reliable knowledge to everyone) in lieu of prematurely adopting regulations. The IHRMP is grounded in the naive belief that if people fully understand the consequences of resource management practices, they will do the right thing and find ways to cooperate. So far this has turned out to be true.

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LITERATURE CITED

Allen, B.H., B.A. Holzman, and R.R. Evett. 1991. A classification system for California's hardwood rangelands. Hilgardia 59(2):1-45.

Bartolome, J.W. 1989. Ecological history of the California Mediterranean-type landscape. In: W. J. Clawson (ed.) Landscape ecology: study of Mediterranean grazed ecosystems. Proc. MAB Symp., XVI Int. Grassl. Congress, Nice, France, Oct 7, 1989, pp.2-15.

Bartolome, J.W., P.C. Muick, and M.P. McClaran. 1988. Natural regeneration of Californian hardwoods. In: Plumb, T.R. and N.H. Pillsbury (Tech. Coord.) Proc. Symp. Multiple-use management of California's hardwood resources. USFS Gen. Tech. Rep. PSW-100. pp26-31.

Ewing, R.A., R.N. Tuazon, N. Tosta, L. Huntsinger, R. Marose, K. Nielson, R. Motroni, and S. Turan. 1988. California's forests and rangelands: growing conflict over changing uses. Forest and Rangeland Resources and Planning, California Dept. Forestry and Fire Protection, Sacto, CA 348p.

Frost, W.E. and N.K. McDougald. 1989. Tree canopy effects on herbaceous production of annual rangeland during drought. J. Range Manage. 42:281-283.

Griffin, J.R. 1977. Oak woodland. In: M.G. Barbour and J. Major (eds.) Terrestrial vegetation of California. Wiley Inter-Science, NY pp. 383-415.

Heady, H.F. 1977. Valley grassland. In: M.G. Barbour and J. Major J (eds.) Terrestrial vegetation of California. Wiley Inter-Science, NY pp. 491-514.

Heady, H.F., J.W. Bartolome, M.D. Pitt, M.G.Stroud, and G.D. Savelle. 1991. California prairie. In: R.T. Coupland (ed.) Natural grasslands, Ecosystems of the World, Vol. 8A. Elsevier Sci. Pub. Co., Amsterdam.

McClaran, M.P. and J.W. Bartolome. 1989. Effect of Quercus douglasii (Fagaceae) on herbaceous understory along a rainfall gradient. Madrono 36:141-153.

McCreary, D.D., W.J. Tietje, and P.J. Tinnin (eds.) 1991. Integrated hardwood range management program. Fourth Progress Report. Univ. Calif. Berkeley, CA 27p.

Schmidt, R.H. (ed.) 1988. Integrated hardwood range management program. First Progress Report. Univ. Calif. Berkeley, CA 27p.

Schmidt, R.H. and P.J. Tinnin (eds.) 1989. Integrated hardwood range management program. Second Progress Report. Univ. Calif. Berkeley, CA 24p.

Standiford, R.B. and H.M. Kerner (eds.) 1990. Integrated hardwood range management program. Third Progress Report. Univ. Calif. Berkeley, CA 20p.

Species Composition of Woodland Communities in the Southwest[1]

Rex D. Pieper[2]

Woodland encinal and piñon-juniper communities in southwestern U. S. and northern Mexico are complex structurally because of variations in climate, topography, soils, land use and phytogeographic affinities. Sound management and use of these fragile plant communities requires a basic understanding of the ecology and floristics of the different communities. This paper presents a comparison based on separate studies in New Mexico, southeastern Arizona, and northwestern Chihuahua, Mexico.

In central and western New Mexico, the tree stratum is dominated by species of *Juniperus. Juniperus monosperma* is the most abundant juniperus species in central New Mexico in the Sacramento Mountains and *J. deppeana* is most abundant in the Gila National Forest in western New Mexico. In the Huachuca and Sierra Madre Mountains, the composition of *Juniperus* species is much lower. The *Pinus* taxa of the woodlands change from *P. edulis* in New Mexico to *P. cembroides* in Arizona and Chihuahua. Oak species are largely shrubby (mostly *Quercus undulata*) in the Sacramento Mountains but are generally small trees in western New Mexico, southeastern Arizona and northern Chihuahua. *Quercus arizonica* is relatively abundant in the three western locations but not in the Sacramento Mountains. *Quercus grisea* is abundant in western New Mexico and northern Chihuahua but not in the Huachuca Mountains. Several grass species including *Bouteloua gracilis, B. curtipendula, Muhlenbergia emersleyi, and Piptochaetium fimbriatum* are widespread in these woodlands.

INTRODUCTION

Oak and piñon-juniper woodlands form conspicuous patterns in foothills of southwestern mountains. At first glance these communities appear similar in appearance. The tree stratum is about the same height, but densities vary throughout the range of these woodlands. Shrubby and herbaceous understory vegetation appears similar also. However, on closer inspection one discovers that these woodlands are rather complex floristically. Only a limited number of species occurs as trees or shrubs, but these components vary throughout the Southwest depending on a variety of environmental variables. These variables include elevation, soils, slopes, aspects, past grazing and fire history and geographic location.

These woodland communities occupy large areas in the Southwest. West et al. (1975) estimated that piñon-juniper woodlands occur on 51,000 km^2 (16% of the state) in Arizona and on 83,400 km^2 (27 % of the state) in New Mexico. Garrison and McDaniel (1982) estimated that 29% of the land surface in New Mexico was covered by piñon-juniper vegetation. In Chihuahua, over 20% of the state is covered by woodland vegetation (Perez 1978).

On the large land area represented by these woodlands, several products and uses are represented. These include habitat for game and livestock, fuelwood, fence posts, Christmas trees, poles, wildings, piñon nuts, charcoal, and recreational opportunities (Fowler et al. 1985). However, these woodlands are very fragile and subject to various kinds of disturbance. Fowler et al. (1985) have documented erosion problems associated with piñon-juniper woodlands in New Mexico.

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[1] Paper presented at the Symposium on Ecology and Management of Oak and Associated Woodlands: Perspectives in the Southwestern United States and Northern Mexico, Sierra Vista, AZ, April 27-30, 1992.

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Management and appreciation of these woodlands involves a basic understanding of their ecology. This paper will present a comparative study of several woodlands in the southwestern U. S. and one area in northern Chihuahua, Mexico.

METHODS

Data were taken from several previous studies. Data from the Sacramento Mountains in central New Mexico came from Lymbery (1979), Schott (1984), Rippel (1978) and Wittie (1991). The species list from Fort Stanton, near Capitan, NM, was used for floristic data from the Sacramento Mountains (Lebgue and Allred 1985). Data from the Gila National Forest came from Hill (1990) while that from the Huachuca Mountains in Arizona came from Wentworth (1985). Sierra Madre data came from Perez-Garcia (1978). Floristic data from Cook's Range in south-central New Mexico came from Columbus (1988).

Comparisons of tree and shrub data were mostly based on woody plant composition and density (number/unit area) of all trees. Data on herbaceous species were based on basal cover. Because of the different studies involved and differences in methods for determining basal cover, only general comparisons were made for herbaceous species.

Geographic affinities for all species listed for each area followed procedures described by Columbus (1988). He classified 684 species into 8 phytogeographical provinces delineated by Bowers and McLaughlin (1987) (fig. 1). Each species was listed in each province where it occurs naturally. Some species were listed for all eight physiographic provinces. Columbus (1987) used different floras and especially plant mounts from different herbaria to classify his plants. I used information from Columbus (1987) for those species listed on the study sites included in the present study and occurring on Cook's Range. For species not recorded for Cook's Range, other floras were used to establish natural distribution patterns.

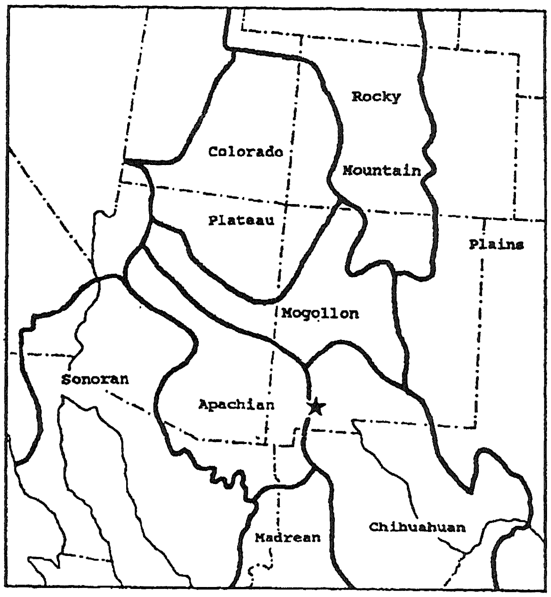

Fig. 1—Floristic provinces (taken from Columbus [1988] after Bowers and McLaughlin [1987]) used in the phytogeographic analysis of native flora of four locations in the Southwest.

Percentages of species representing each floristic province were calculated by adding all occurrence for each province and dividing by the total number of species for that location. For example there were a total of 103 occurrences of species naturally found in the Rocky Mountain Province out of a total of 305 species classified from Ft. Stanton. The calculation 103/305 = 34% frequency for species at Ft. Stanton that naturally occur in the Rocky Mountain Province.

RESULTS

Pinus edulis was the dominant tree species on both New Mexico locations (fig. 2) contributing about 50% of the woody plant composition. Lanner (1975) and Little (1971) show the distribution of *Pinus edulis* as western New Mexico, central and northern Arizona, central and western Colorado and southeastern Utah. In the Huachuca mountains and northern Chihuahua, *Pinus edulis* gives way to *Pinus cembroides* which appears to be more abundant in southeastern Arizona than in northern Chihuahua (fig. 2). *Pinus edulis* was not listed for either the

Arizona or Chuhuahuan location. These data agree with those from the Huachuas by Wallmo (1955) and Moir (1979) for the Peloncillo Mountains on the New Mexico-Arizona border. *Pinus discolor* occurred in certain habitats in the Gila National Forest, but was somewhat limited in distribution (Hill 1990). Lanner (1981) indicated that originally *Pinus edulis* and *P. discolor* were considered varieties of *P. cembroides* but have since been elevated to species status.

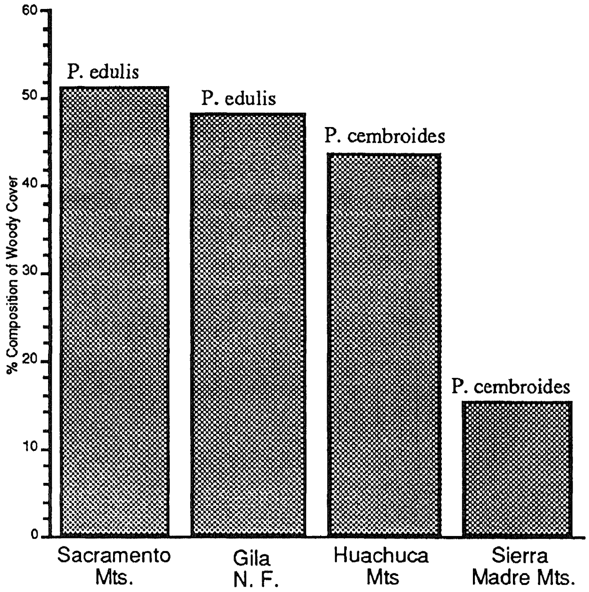

Fig. 2—Composition of *Pinus edulis* and *P. cembroides* at four locations in the Southwest.

Juniperus species contributed over 25% of total canopy cover on both New Mexico sites (fig. 3) but less than 10% on the Arizona and Chihuahua sites. In the Sacramento mountains, *Juniperus monosperma* is most abundant and *J. deppeana* is widely distributed, but not abundant (Kennedy 1983). In the Gila National Forest *J. deppeana* is co-dominant with *Pinus edulis* and is the most abundant juniper followed by *J. erythrocarpa, J. osteosperma, J. monosperma, and J. scopulorum* (Hill 1990).

The only widespread oak species in the Sacramento Mountains was *Quercus undulata.* This species apparently resulted from hybridization of several (at least 8) oak species with *Q. gambelii* (Tucker et al.1961, Tucker 1963). In the Sacramento Mountains, *Q. undulata* occurs mostly as a shrub, but occasionally as a small tree. Both *Q. grisea* and *Q. gambelii* were listed in the flora for Fort Stanton (Lebgue and Allred 1985), but are not very abundant. *Q. grisea* is much more abundant in the Gila National Forest and Sierra Madre Mountains (fig. 4). However, *Q arzonica* is an important component of woodland vegetation in western New Mexico, eastern Arizona and the Sierra Madre Mountains (fig. 4).

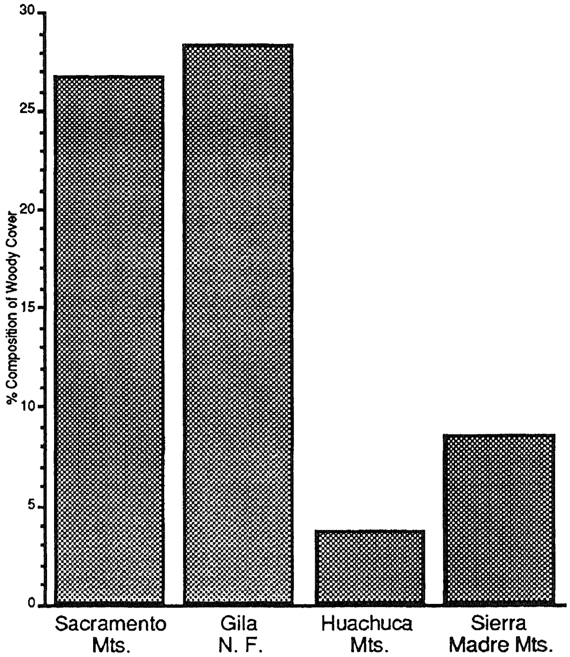

Fig. 3—Composition of *Juniperus* species at four locations in the Southwest.

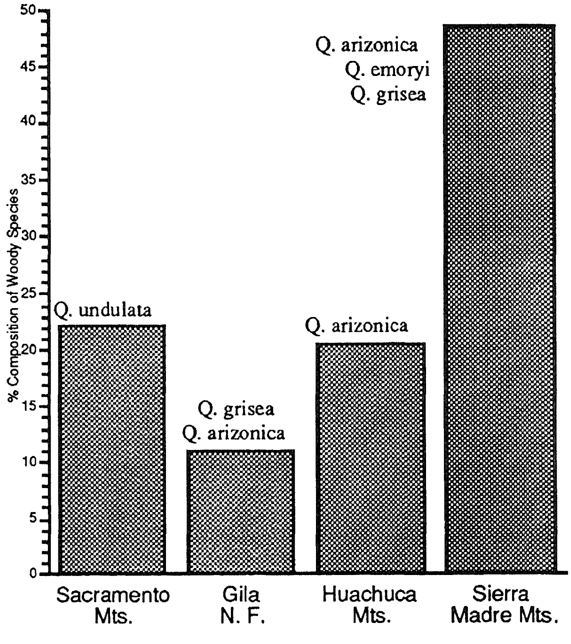

Fig. 4—Composition of oak species (*Quercus*) at four locations in the Southwest.

Cercocarpus montanus and *Rhus trilobata* were the only shrubs besides the oaks found on all 4 locations (table 1). *Cercocarpus montanus* was present in small quantities in the Sacramento and Sierra Madre Mountains while *Rhus trilobata* was more abundant in the Sacramento and Huachuca Mountains.

Table 1.--Percent canopy cover of major shrub species at 4 locations in the Southwest

Species	Sacramento Mts.	Gila N.F.	Huachuca Mts.	Sierra Madre
Cercocarpus montanus	0.1	1.9	9.1	0.2
Garrya wrightii	0	0.1	4.5	0
Rhus trilobata	1.1	0.2	0.9	0.4
Arctostaphylos pungens	0	0.4	0	0.2
Opuntia imbricata	0.4	0	0	0.01

Four grass species, *Bouteloua gracilis, Bouteloua curtipendula, Muhlenbergia emersleyi,* and *Piptochaetium fimbriatum* occurred on three locations where understory grass species were sampled (table 2). *Bouteloua gracilis* was the dominant understory grass species in the Sacramento Mountains and the Gila National Forest, but contributed only 1.6% basal cover in the Sierra Madre Mountains. However, there is a distinct zonation pattern of herbaceous species around individual *Pinus edulis* and *Juniperus monosperma* trees with *Bouteloua gracilis* more abundant in the interspaces (Armentrout and Pieper 1988). Basal cover of *Muhlenbergia dubia* exceeded 2% cover in the Sacramento Mountains and the Gila National Forest but was not sampled in the Sierra Madre Mountains. *Andropogon gerardii* was one of the most abundant grass species at the Sierra Madre location, but was absent at the other locations. *Andropogon gerardii* is a major component of tall grass vegetation in the U. S. where precipitation is fairly high (from about 40 to over 80 cm annually) (Risser et al. 1981). Precipitation in oak woodlands in the Sierra Madre Mountains varies from less than 30 cm annually to over 100 cm at higher elevations (Perez-Garcia 1978). *Andropogon gerardii* is found in the Sacramento Mountains at Fort Stanton (Lebgue and Allred 1985), but is not abundant under piñon-juniper canopies (Armentrout and Pieper 1988).

Table 2.--Basal area (%) of important understory grass species in woodlands of 3 locations in the Southwest

Species	Fort Stanton	Gila N. F.	Sierra Madre
Bouteloua gracilis	25.6	17.0	1.6
Bouteloua curtipendula	2.3	5.8	1.0
Bouteloua hirsuta	0	2.7	0.5
Muhlenbergia dubia	2.0	2.5	0
Muhlenbergia montanus	0	2.9	1.0
Muhlenbergia emersleyi	0.5	1.2	1.3
Muhlenbergia pauciflora	1.5	0	0
Muhlenbergia rigida	0	0	1.2
Poa fendleriana	0	2.4	0
Piptochaetium fimbriatum	1.2	1.6	0.1
Andropogon gerardii	0	0	1.9

The Ft. Stanton flora appeared to have the widest representation from different floristic provinces (fig. 5). Only Sonoran species were poorly represented with 13% of the flora coming from this province. Representatives from the Sonoran Province was also poorly represented on the other study locations. On Cooke's Range 24% of the species came from the Sonoran Province, the highest for any of the study locations. Species from the Colorado Plateau, Mogollon, Apachian, and Chihuahuan provinces were well represented at Fort Stanton. The Chihuahuan and Apachian species were best represented in the native flora from Cook's Range. Gila National Forest flora had most species representing the Apachian and Chihuahuan provinces followed by the Mogollon and Colorado Plateau. These data also indicate the proximity of the Gila National Forest to both The Apachian and Mogollon Provinces. The Apachian and Madrean species were highly represented in the flora of the Sierra Madre Mountains indicating this southern location. Rocky Mountain, Plains, and Sonoran species were poorly represented at this Chihuahuan location.

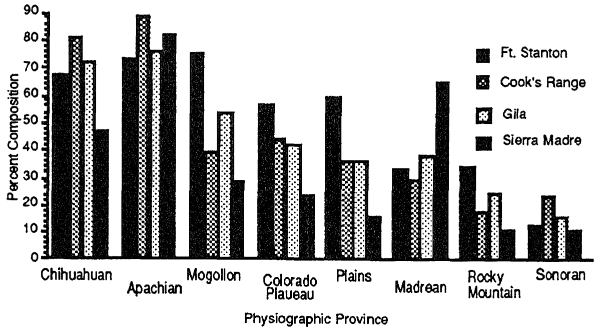

Fig. 5—Percentages of species representing floristic provinces in the southwestern U.S. and northern Mexico based on the total flora at four locations in the U.S. and Mexico.

DISCUSSION

Woodland vegetation in New Mexico except for the extreme southwestern corner appears to be typical piñon-juniper woodland. However, in western New Mexico and eastern Arizona oak species become more prominent. In northern Chihuahua oak species become dominant with pine and juniper species subordinate. Thus these woodlands represent a transition from evergreen woodlands dominated by *Juniperus* and *Pinus* species to a deciduous woodland dominated by *Quercus* species. Even within the evergreen and deciduous woodlands, there are shifts in species composition from on location to another. These vegetational patterns are probably related to historical as well as present environmental characteristics.

LITERATURE CITED

Armentrout, S. M. and R. D. Pieper. 1988. Plant distribution surrounding Rocky Mountain pinyon pine and oneseed juniper in south-central New Mexico. J. Range Manage. 41:139-143.

Bowers, J. E. and S. P. McLaughlin. 1987. Flora and vegetation of the Rincon Mountains, Pima County, Arizona. Desert Plants. 8:51-94

Columbus, J. T. 1988. flora of Cooke's Range, Southwestern New Mexico. M. S. Thesis, New Mex. State Univ. Las Cruces, NM.

Fowler, J. M., K. E. Peacock and M. J. Schaber. 1985. Pinyon-juniper woodland type in New Mexico—asset or liability? New Mex. State Univ. Agr. Exp. Sta. Bull. 718.

Garrison,G. L. and K. C. McDaniel. 1982. New Mexico brush inventory. New Mex. Dept. Agr. Spec. Rep. No. 1.

Hill, A. 1990. Ecology and classification of the pinyon-juniper woodlands in western New Mexico. Ph.D. Dissertation. New Mex. State Univ., Las Cruces, NM.

Kennedy, K. L. 1983. A habitat type classification of the pinyon-juniper woodlands of the Lincoln National Forest. *In*: Moir, W. H. and L. Hendzel (Cords.). Proc. Workshop on Southwestern Habitat Types. U. S. Forest Serv. Albuquerque, NM.

Lanner, R. M. 1975. Piñon pines and junipers of the southwestern woodlands. *In*: Proc. Symposium on pinyon-juniper ecosystems. Utah State Univ., Logan, UT.

Lanner, R. M. 1981. The piñon pine. A natural and cultural history. Univ. Nevada Press. Reno, NV.

Lebgue, T. and K. W. Allred. 1985. Flora of the Fort Stanton Experimental Ranch, Lincoln County, New Mexico. New Mex. State Univ. Agr. Exp. Sta. Res. Rep. 557.

Little, E. L. 1977. Research in the pinyon-juniper woodland. *In:* Aldon, E. F. and T. J. Loring (Tech. Coords.). Ecology, uses, and management of pinyon-juniper woodlands. U. S. For. Ser. Gen. Tech. Rep. RM - 39.

Lymbery, G. A. 1979. Ecology of pinyon-juniper vegetation in south-central New Mexico. Ph. D. Dissertation. New Mex. State Univ., Las Cruces, NM.

Lymbery, G. A. and R. D. Pieper. 1983. Ecology of pinyon-juniper vegetation in the northern Sacramento Mountains. New Mex. State Univ. Agr. Exp. Sta. Bull. 698.

Moir, W. H. 1979. Soil-vegetation in the central Peloncillo Mountains, New Mexico. Amer. Midl. Natur. 102:317-331.

Perez-Garcia, A. 1978. Ecology of the oak communities on the eastern foothills of the Sierra Madre Occidental in Chihuahua. Ph. D. Dissertation. New Mex. State Univ., Las Cruces, NM.

Rippel, P. D. 1978. Cabling in the pinyon-juniper range of south-central New Mexico. M. S. Thesis. New Mex. State Univ., Las Cruces, NM.

Schott, M. R. 1984. Pinyon-juniper ecology with emphasis on secondary succession. Ph. D. Dissertation. New Mex. State Univ, Las Cruces, NM.

Tucker, J. M., W. P. Cottam, and R. Drobnick. 1961. Studies in the *Quercus undulata* complex. II. The contribution of *Quercus turbinella*. Amer. J. Bot. 48:329-339.

Tucker, J. M. 1963. Studies in the *Quercus undulata* complex. III. The contribution of *Quercus arizonica*. Amer. J. Bot. 50:699-708.

Wallmo, O. D. 1955. vegetation of the Huachuca Mountains, Arizona. Amer. Midl. Natur. 54: 466-480.

Wentworth, T. R. 1985. vegetation on limestone in the Huachuca Mountains, Arizona. Southw. Nat. 30:385-395.

West, N. E., K. H. Rea, and F. J. Tausch. 1975. Basic synecological relationships in pinyon-juniper woodlands. *In*: A symposium on the pinyon-juniper ecosystem. Utah State Univ., Logan, UT.

Wittie, R. D. 1991. Assessment of an integrated tebuthiuron-fire management system for pinyon-oneseed juniper woodlands in south-central New Mexico. Ph. D. Dissertation, New Mex. State Univ., Las Cruces, NM.

Use of Oak and Associated Woodlands by Mexican Spotted Owls in Arizona[1]

Joseph L. Ganey,[2] Russell B. Duncan,[3] and William M. Block[2]

Abstract. – Although the spotted owl is often associated with coniferous forests, oak and associated woodlands also provide habitat for spotted owls. In Arizona, Mexican spotted owls are year-round residents in Madrean oak-pine forests, encinal woodlands, and ponderosa pine-Gambel oak forests, while some spotted owls winter in pinyon-juniper woodlands. Oak and associated woodlands present unique management challenges to resource managers charged with maintaining viable populations of Mexican spotted owls.

INTRODUCTION

The spotted owl (*Strix occidentalis*) is associated with mature coniferous forests throughout much of its range (Gould 1977, Forsman et al. 1984, Ganey and Balda 1989a, Thomas et al. 1990). Hardwoods, however, may also provide important habitat elements for spotted owls. For example, the northern spotted owl (*S. o. caurina*) occurs not only in coniferous forests but also in mixed-evergreen forests containing various hardwoods in the understory (Gould 1977, Forsman et al. 1984, Solis and Gutiérrez 1990). Hardwoods contribute to canopy closure and layering thought to be important in providing a cool microclimate for spotted owls (Barrows 1981), and hardwoods are used frequently by roosting owls during warm weather (Barrows 1981, Forsman et al. 1984).

The California spotted owl (*S. o. occidentalis*) also occupies hardwood stands and mixed-evergreen stands, often roosting in understory hardwoods during warm weather (Bent 1938, Gould 1977, Barrows 1981, Gutiérrez and Pritchard 1990). Canyon live oak (*Quercus chrysolepis*) was the dominant tree species in 91% of the areas where Gould (1977) found this owl below 1100 m in the southern coast ranges of California. Gutiérrez and Pritchard (1990) found 17 of 40 spotted owl roosts in hardwood or conifer-hardwood stands in southern California. Many spotted owls in the Sierra Nevada apparently migrate from breeding areas in coniferous forest to lower-elevation wintering areas in oak-pine (*Pinus*) woodlands (Laymon 1989, Verner et al. 1991), and some owls reside in such woodlands throughout the year (Verner et al. 1991).

The Mexican spotted owl (*S. o. lucida*) also uses hardwoods (Bent 1938, Ganey and Balda 1989a, Dargan 1992, Duncan and Taiz, in press). Because of concerns over habitat loss and possible population declines, this subspecies was listed as threatened by the state of Arizona (Arizona Game and Fish Department 1988) and was proposed for listing as threatened by the U.S. Fish and Wildlife Service (Federal Register 56:56344-56355). Information on the habitat requirements of this owl is critical to developing sound management strategies for the maintenance of viable populations. Here, we provide preliminary information on the use of oaks and associated woodlands by Mexican spotted owls in Arizona. Our intent is to alert resource managers to the potential importance of these habitats to Mexican spotted owls.

MADREAN EVERGREEN FOREST AND WOODLAND

South of the Mogollon Rim in Arizona, spotted owls are found in montane conifer forests and in Madrean evergreen forest and woodlands (Marshall 1957, Ganey and Balda 1989a, Duncan and Taiz, in press). Madrean evergreen habitats occupied include the Encinal (oak) Series, Oak-pine Series, and Cypress Series (vegetation types throughout follow Brown 1982). Encinal is dominated by a variety of evergreen oaks, sometimes co-occurring with Mexican pinyon (*P. cembroides*) and alligatorbark juniper (*Juniperus deppeana*). Tree height is typically <15 m, with an open canopy. Oak-pine forest is dominated by trees >15 m in height with a closed, multilayered canopy. The overstory typically consists of Chihuahua (*P. leiophylla*), Apache (*P. engelmannii*), ponderosa (*P. ponderosa*), and/or southwestern white pine (*P. strobiformis*), with evergreen oaks common in the understory. Relict stands of Arizona cypress (*Cupressus arizonica*) sometimes occupy cool microsites within areas dominated by oak-pine forest, and deciduous riparian trees may occur in drainage bottoms within both encinal and oak-pine forest (Brown 1982).

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[1] *Poster presented at symposium, Ecology and Management of Oak and Associated Woodlands: Perspectives in the Southwestern United States and Northern Mexico (Sierra Vista, AZ, April 27-30, 1992).*

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Habitat use by Mexican spotted owls in southern Arizona has not been intensively studied, and the importance of these habitats to the owl is unknown. However, of 64 sites where Ganey and Balda (1989a) located spotted owls roosting in southern Arizona, 19 (30%) were in oak-pine forest and 9 (14%) were in encinal woodland (fig. 1). Duncan and Taiz (in press) reported that oak-pine and Arizona cypress forests were prominent components of the "core area" of 13 (68%) of 19 management territories established for spotted owls on the Coronado National Forest. Core area and management territory as used in this paper refers to a management designation, however (see Federal Register 54:27416-27418 for clarification). These areas are sometimes delineated without detailed knowledge of owl movements, and that delineation may not provide much insight into which available habitats are used by owls.

PONDEROSA PINE-GAMBEL OAK FOREST

North of the Mogollon Rim in Arizona, most spotted owls occur in montane conifer forest, particularly the Mixed Conifer Series dominated by Douglas-fir (*Pseudotsuga menziesii*) and/or white fir (*Abies concolor*) (Ganey and Balda 1989a). Spotted owls also breed in ponderosa pine-Gambel oak forest (*Q. gambelii*; Pine series, Ponderosa pine-Gambel oak Association) in north-central Arizona. Gambel oak is often common in both habitat types. For example, ponderosa pine/oak or oak was listed as the dominant or codominant habitat type within the core area at 50 of 113 management territories established for spotted owls on the Coconino National Forest, Arizona (Dargan 1992).

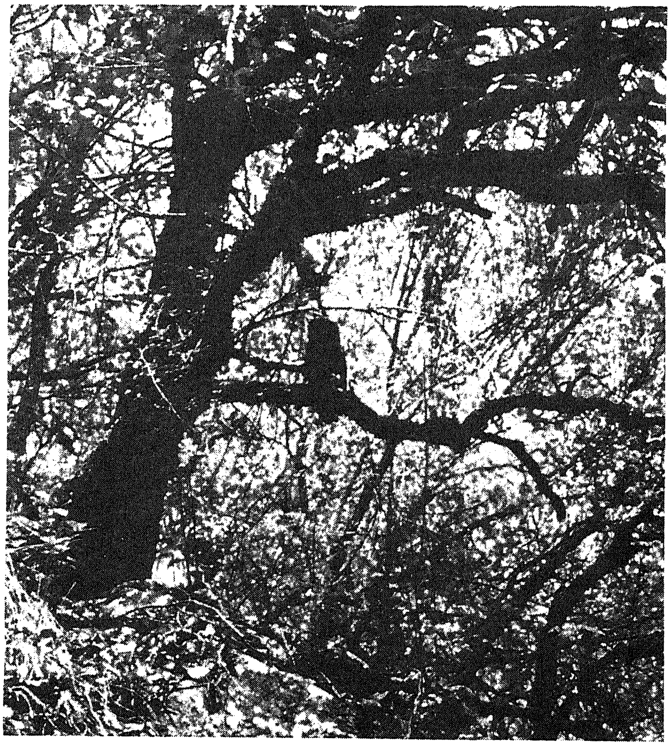

Figure 1. Mexican spotted owl roost in Madrean oak-pine forest, Chiricahua Mountains, Arizona (photo by Russell B. Duncan).

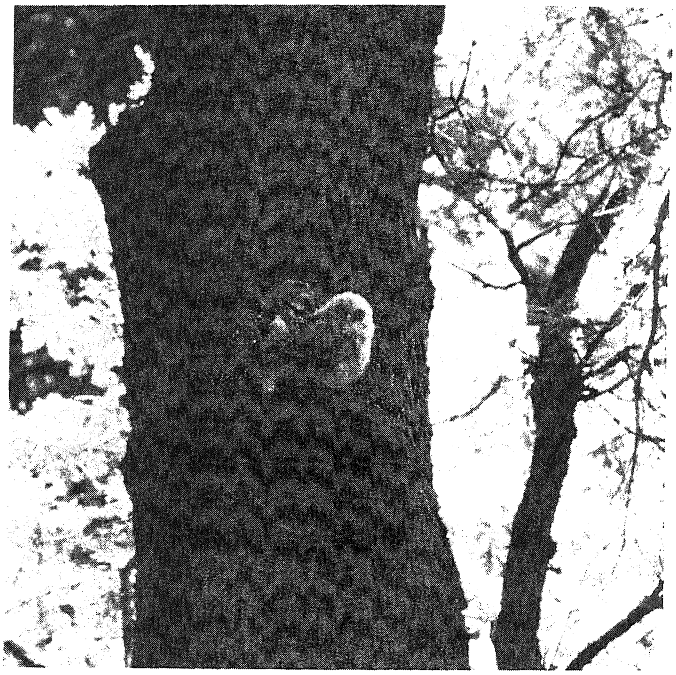

Figure 2. Adult and juvenile Mexican spotted owl perched near their nest, a cavity in a large Gambel oak tree, Coconino National Forest, north-central Arizona (photo by Joseph L. Ganey).

Spotted owls occupying ponderosa pine-Gambel oak forest are typically found in stands containing well-developed understories of Gambel oak. These understories contribute to relatively high canopy closures for ponderosa pine stands (table 1). The oak component also contributes to stand density and basal area (table 1). Oak trees provide large horizontal limbs for perching and nest sites in the form of large cavities. In an ongoing radiotelemetry study of 13 spotted owls in ponderosa pine-Gambel oak forest, 3 of 6 nests used were in cavities in large Gambel oak trees (fig. 2). In addition, 56 (16%) of 342 roosts

Table 1. – Selected habitat characteristics of 18 Mexican spotted owl roost sites in ponderosa pine-Gambel oak forest on the Coconino National Forest, Arizona (Mormon Lake and Long Valley Ranger Districts). Characteristics were measured on circular plots (0.04 ha) centered on the roost tree.

Variable	Mean	Standard error	Range
Canopy closure (%)	80.1	1.4	69.0-94.0
Oak density (trees/ha)[1]	656.3	135.1	74.1-2568.8
% of total density consisting of Gambel oak	51.0	6.2	10.0-95.4
Oak basal area (m²/ha)	24.3	2.3	9.9-37.9
% of total basal area consisting of Gambel oak	41.7	4.0	18.9-83.2
Oaks/ha >50 cm d.b.h.	2.0	0.5	0.0-9.0

[1] Trees defined as stems >10 cm diameter at breast height (d.b.h.) and >2 m in height.

observed were in oak trees. Gambel oak was used mostly during the summer months; 43 (47%) of 91 roosts located from June through September were in Gambel oak trees.

PINYON-JUNIPER WOODLANDS

Although many Mexican spotted owls remain on their breeding areas throughout the year, some migrate during the winter (Ganey and Balda 1989b). During the winters of 1990-91 and 1991-92, two radio-tagged owls (one each winter) in northern Arizona migrated from breeding areas in ponderosa pine-Gambel oak forest (elevation 2290 m) approximately 40 km to pinyon-juniper woodland (Great Basin conifer woodland, Pinyon-juniper series; elevation 1370 m). These owls left the breeding areas in late December and returned from early to late March. Other owls have been known to migrate as early as mid-November and return as late as early April (Ganey and Balda 1989b). The number of owls that migrate downslope is currently unknown and may vary among years. The factors guiding choice of a wintering area are also unknown, although all documented wintering areas are below the level of persistent snow.

RESEARCH NEEDS AND MANAGEMENT CHALLENGES

Management of oak and associated woodlands used by spotted owls presents resource managers and researchers with unique challenges. Management concerns relating to spotted owls have typically centered around timber harvest and the loss of mature or old-growth stands. Many spotted owls in the ponderosa pine-Gambel oak forest type occupy stands with many snags and down logs, pronounced canopy layering, and large oak trees (Dargan 1992). Regeneration of stands containing these habitat components will be a challenge to silviculturists.

Fire management in these stands presents another challenge. Decades of fire suppression have allowed fuels to accumulate. As a result, these stands are vulnerable to destruction by fire (Dargan 1992). One recent prescribed burn within a spotted owl territory removed virtually all logs and oak snags and most of the live oak trees (S. J. Nagiller and T. Randall-Parker, Coconino National Forest, personal communication, 1992).

Management of fuelwood harvest presents yet another important challenge. Oak, pinyon, and juniper are all popular fuelwoods, and demand exceeds supply in some areas (Dargan 1992). Fuelwood harvest could alter habitat suitability for spotted owls, particularly if large trees containing nest cavities are harvested. Illegal cutting of large oak trees in ponderosa pine-Gambel oak forest is a serious problem (Dargan 1992).

Management of winter habitat will also be challenging for resource managers. At present, little is known concerning how owls select wintering areas or use habitat within these areas. Some wintering habitat includes a mosaic of federal, state, and privately owned lands. This mosaic will complicate the planning and implementation of management activities (Laymon 1989).

Studies currently underway will provide resource managers with some of the information needed to answer these challenges. The U.S. Forest Service is conducting population surveys to document how much spotted owls use these habitats. The Rocky Mountain Forest and Range Experiment Station is studying home range size and habitat use by radio-tagged spotted owls in ponderosa pine-Gambel oak forest. This study should provide quantitative information useful in management of both fuelwood and timber harvest. In addition, monitoring of radio-tagged owls migrating to lower elevations will provide information on habitat use within wintering areas. Telemetry studies of habitat use in the mountains of southern Arizona would also be valuable.

Clearly, much remains to be learned regarding the ecology of Mexican spotted owls in oak and associated woodlands and the importance of such habitats to owl populations. Specific management recommendations must await the results of current studies. In the meantime, we urge resource managers to be aware that spotted owls occupy these habitats and to consider the potential impacts of management activities on spotted owls.

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LITERATURE CITED

Arizona Game and Fish Department. 1988. Threatened native wildlife in Arizona. Arizona Game and Fish Department, Phoenix, AZ. 32 pp.

Barrows, C.W. 1981. Roost selection by spotted owls: an adaptation to heat stress. Condor 83:302-309.

Bent, A.C. 1938. Life histories of North American birds. U.S. National Museum Special Bulletin 1. 446 pp.

Brown, D.E., ed. 1982. Biotic communities of the American Southwest - United States and Mexico. Desert Plants 4:1-342.

Dargan, C. 1992. Spotted owl surveys: 1991. USDA Forest Service, Coconino National Forest, Flagstaff, AZ.

Duncan, R.B., and J.D. Taiz. In press. A preliminary understanding of spotted owl distribution in the Chiricahua Mountains and associated sub-Mogollon mountain ranges in southern Arizona. Proc. Chiricahua Mountains Research Symp., Southwest Parks and Monuments Press, Tucson, AZ.

Forsman, E.D., E.C. Meslow, and H.M. Wight. 1984. Distribution and biology of the spotted owl in Oregon. Wildlife Monograph 87. 64 pp.

Ganey, J.L., and R.P. Balda. 1989a. Distribution and habitat use of Mexican spotted owls in Arizona. Condor 91:355-361.

Ganey, J.L., and R. Balda. 1989b. Home range characteristics of spotted owls in northern Arizona. Journal of Wildlife Management 53:1159-1165.

Gould, G.I. Jr. 1977. Distribution of the spotted owl in California. Western Birds. 8:131-146.

Gutiérrez, R.J., and J. Pritchard. 1990. Distribution, density, and age structure of spotted owls on two southern California habitat islands. Condor 92:491-495.

Laymon, S.A. 1989. Altitudinal migration movements of spotted owls in the Sierra Nevada, California. Condor 91:837-841.

Marshall, J.T. Jr. 1957. Birds of the pine-oak woodland in southern Arizona and adjacent Mexico. Pacific Coast Avifauna 32:1-125.

Solis, D.M. Jr., and R.J. Gutiérrez. 1990. Summer habitat ecology of northern spotted owls in northwestern California. Condor 92:739-749.

Thomas, J.W., E.D. Forsman, J.B. Lint, E.C. Meslow, B.R. Noon, and J. Verner. 1990. A conservation strategy for the northern spotted owl. Report of the Interagency Scientific Committee to address the conservation of the northern spotted owl.

Verner, J., G.N. Steger, G.P. Eberlein, D.A. Leal, and T.E. Munton. 1991. Annual progress report. Part 1: Spotted Owl home-range size and composition in the Sierra National Forest. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Fresno, CA.

Importance of the Sierra de la Laguna Woodlands for Conservation of Endemic Species of Mexico[1]

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In all the State of Baja California Sur there exists only one place where it is possible to find oak woodlands: at la Sierra de la Laguna. The importance of such forests from the socioeconomic and biological point of view are discussed. Most of the pluvial precipitation of the State occur in such woodlands which enable the present arrangement of the main human settlements of Baja California Sur and their main possibilities of development. Also, such ecosystems harbors most of the biological diversity of all the State. Because the high incidence of endemic in such forests these can also be considered as very important for the humanity heritage.

INTRODUCTION

The only oak woodlands of all the State of Baja California Sur, located in Northern México, are these occupying the upper parts of the Sierra de La Laguna. The Sierra de La Laguna is located between the parallels 22° 50' N and 24° N and by the meridians 109° 59' W and 110° 10' W. (Fig. No. 1). In those mountains, between 800 and 1,800 m it is found an oak forest covering an approximated area of 20,000 hectares. Between the 1,800 and 2,000 m it occurs the oak-pine forests which covers approximately 10,000 hectares.

The oak forest is dominated by *Quercus devia* and *Q. tuberculate* and the oak-pine forest also by *Pinus lagunae*. Another species found in these woodlands are *Arbutus peninsularis* and *Nolina beldingii*. (Arriaga and Ortega. 1988).

The oak and oak-pine forests of the Sierra de La Laguna were separated from the mainland during the middle miocene (Padilla *et al.* 1988) allowing thus the establishment of an endemic species evolutionary center, because it is until the pliocene when these mountains were definitively attached to the peninsula which attained its present geographic configuration.

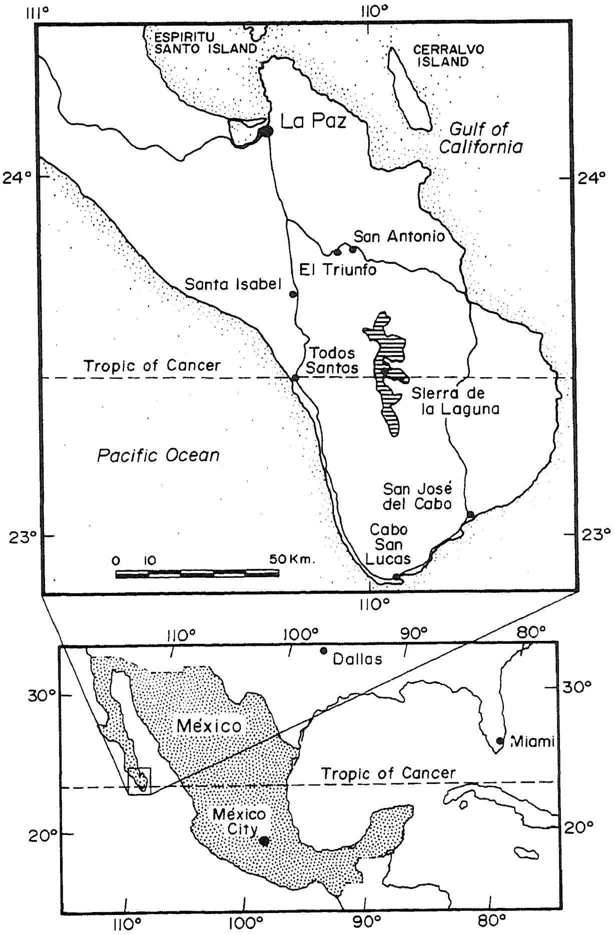

Figure 1. Location of the Sierra de la Laguna.

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[1] Paper presented at the symposium on Ecology and Management of oak and other woodlands in the Southwestern United States and Northern Mexico I, Sierra Vista, April 27-30, 1992.

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In this paper we try to outline the biological and socioeconomic importance of such woodlands for the State and northern México.

METHODS

After an extense bibliographic revision and consultation with the specialists of our Research Center, we proceed to identify the ocurrence of endemic species at the oak and oak-pine forests of the Sierra de La Laguna. Also, we reviewed the development plans of the State, concerning the programed population and touristic infrastructure growth by regions.

RESULTS

The Sierra de La Laguna ecosystems not only harbors the greatest biological diversity of all the State of Baja California Sur, but also in these woodlands, proportionately of their surface, occurs the majority of endemic species and subspecies of all the peninsula (Fig. 2). For instance at the oak and oak-pine forest there exist a total of 250 species, from which 45 are endemic (Table 1).

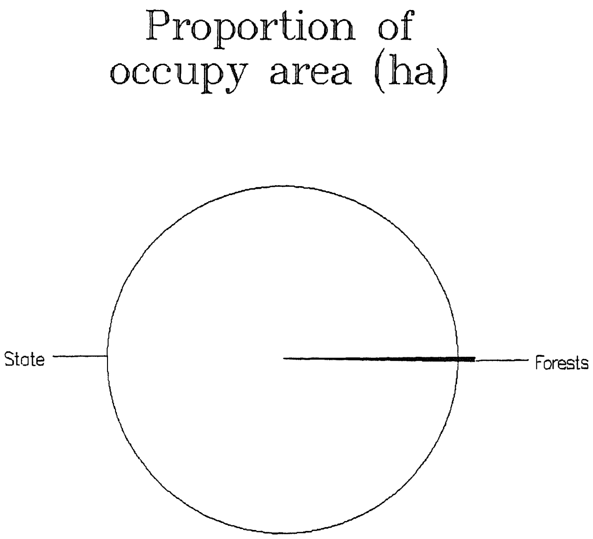

Figure 2. Relation of State-Forests surface.

Concerning the animals only, taking into account the vertebrates, it is possible to observe that these woodlands represent the habitat for most of the endemic species and subspecies of all the State (Table 2).

Up to the present the conservation conditions of the natural resources of the Sierra de La Laguna are well preserved. Mainly because its geographical isolation and the low demographic density of the Baja California Sur State.

Table 1. Flora diversity synopsis of the oak and oak-pine forests of the Sierra de La Laguna (From León *et al.* 1988)

Taxonomical category	Forests	State
Families	62	
Genera	168	
of Species	250	1300
endemic species	45	300

However, up to this date these ecosystems have not any legal protection. Thus, taking into account the uniqueness of the oak woodlands of Baja California Sur; their fragility because as any insular system the competitive abilities of their species are reduced, and they have a great susceptibility to foreign predators and low regeneration rates (Arriaga y Ortega, 88); and because of their lack of legal protection, it is possible to conclude that these woodland ecosystems are not only important as an aquifers recharge zone but also a key area to protect most of the biological diversity of the State.

Table 2. Vertebrate fauna diversity of the oak and oak-pine forests of the Sierra de La Laguna.

Taxonomical category	Forests	State
Amphibia		
Total number of species	2	4
endemic species	0	0
Reptilia		
Total number of species	22	56
Endemic species	10	19
Endemic subspecies	7	
Avian		
Total number of species	24	115
Endemic species	1	41
Endemic subspecies	11	
Mammalia		
Total number of species	14	58
Endemic species	0	6
Endemic subspecies	4	

The oak and oak-pine forests of the Sierra de La Laguna are also important from the socioeconomic point of view, in these forests are gathered the greatest levels of pluvial precipitation of all the State of Baja California Sur: 750 mm yearly (Ortega y Arriaga, 1988).

The existence of the mountains with such woodlands makes possible the posterior utilization of the gathered water because most of it is infiltrated to the subterranean reservoirs, from which it is later extracted at the lower parts of the mountains. Most of the population of Baja California Sur State is concentrated in a radius of no more than 80 kilometers from the Sierra de la Laguna, mainly at La Paz and Los Cabos. In this zone, also, is programed most of the future development of the State.

CONCLUSIONS

The main problem of Baja California Sur is water availability. Thus, if these oak woodland forest are destroyed unexpected consequences will occur with the present distribution of the human settlements of the State and also with the future possibilities of development.

In spite of their biological and socioeconomic importance, up to the present the Sierra de La Laguna woodlands has not any legal protection. We recommend strongly the promotion of a formal decree that enable the protection of these woodlands.

ACKNOWLEDGEMENTS

This work was supported by the Centro de Investigaciones Biológicas de Baja California Sur, the Consejo Nacional de Ciencia y Tecnología of México and the World Wildlife Fund.

We would like to thank Dr. Peter F. Ffolliott and Dr. Martin Fogel for their academic support during this work.

LITERATURE CITED

Arriaga L. and A. Ortega. 1988. La Sierra de la Laguna de Baja California Sur. Centro de Investigaciones Biológicas de Baja California Sur. Pub. No. 1. 237 pp.

Padilla G., S. Pedrín and E. Díaz. 1988. Historia Geológica y Paleoecología. In: Arriaga L. and A. Ortega Eds. La Sierra de la Laguna de Baja California Sur. Centro de Investigaciones Biológicas de Baja California Sur. Pub. No. 1. 237 pp.

León L., R. Domínguez and R. Coria. 1988. Aspectos Florísticos In: Arriaga L. and A. Ortega Eds. La Sierra de la Laguna de Baja California Sur. Centro de Investigaciones Biológicas de Baja California Sur. Pub. No. 1. 237 pp.

Ortega A. and L. Arriaga. 1988. Consideraciones Finales. In: Arriaga L. and A. Ortega Eds. La Sierra de la Laguna de Baja California Sur. Centro de Investigaciones Biológicas de Baja California Sur. Pub. No. 1. 237 pp.

Structural Diversity in Oak Woodlands of Southeastern Arizona[1]

James W. Sharman and Peter F. Ffolliott[2]

Measurements of tree characteristics were used as indicators of overstory structure on four oak woodland sites. Three areas harvested at different times and intensities were compared with an undisturbed area to assess effects of harvesting on various structural attributes of woodland overstories. Differences were found for some woodland structural characteristics between harvested areas and the undisturbed area. Structural changes persist, as prolific coppice sprouting initially produces more shrub-like trees, which appear to take a relatively long time to reach mature height and form.

INTRODUCTION

The oak woodlands of southeastern Arizona are coming under increasing pressure to provide resources within a multiple-use context. Historically, these woodlands were utilized by mining operations and increasingly have become relied upon as a source of residential fuelwood. Bahre (1991) found little evidence of major changes in areal extents or distributions of the woodlands due to cutting, but he noted changes to overall woodland structure. Grazing, woodcutting, range improvement, and alterations in fire ecology have been identified as current and historic factors influencing woodland ecology (Bahre and Hutchinson 1985).

Until recently, little attention had been devoted to these woodlands due to their low potential for commercial exploitation. Natural resource managers, therefore, are working with an information deficit. Oak woodlands, in addition to providing fuelwood, support a wide variety of wildlife, including non-game species. Over 180 different birds and mammals reportedly utilize oak products (Van Dersal 1940). As wildlife habitats, the woodlands are a mosaic of structural elements which reflects availability of critical habitat resources. Vertical structure influences photosynthetic, nutrient, and water movement efficiency, and is correlated with wildlife habitats and biodiversity.

Structural diversity has been defined as the abundance of foliage in vertical layers of a habitat (Magurran 1988). Indirect measures of animal species richness have been tied to habitat features such as woodland structure (Kirby 1986). In support of the hypothesis linking resource availability and community structure, MacArthur and MacArthur (1961) found a positive correlation between bird species diversity (BSD) and foliage height diversity (FHD). Some investigators have confirmed this BSD-FHD relationship (MacArthur et al. 1962; Karr and Roth 1971), others have not (Balda 1969; Engstrom, et al. 1984; Erdelen 1984). These latter investigators suggest that floristics also are important as habitat selection factors.

Balda (1969) found that oak was used heavily by bird species in a pine-oak woodland in southeastern Arizona, and that foliage height distribution was a predictor of bird use. In a 1975 study, he suggested that total height might be a reflection of the physiologically active volume of canopy producing new growth, flowers, and fruits attractive to birds and also to insects eaten by birds

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[1] Paper presented at the symposium on the Ecology and Management of Oak and Associated Woodlands: Perspectives in the Southwestern United States and Northern Mexico. [Sierra Vista, Arizona, April 27-30, 1992]

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(Balda 1975). Mills et al. (1991) also suggested that total vegetative volume is an estimator of available resources, which can be correlated with breeding bird density. Since fuelwood harvests impact woodland physiognomy, it is incumbent on managers to evaluate possible ramifications of this activity.

DESCRIPTION OF STUDY

The objectives of this study were to characterize oak woodland structure, determine effects of fuelwood harvesting on oak woodland structure, identify trends in woodland structural response to harvest over time, and suggest management implications.

Study Area

Oak woodlands of southeastern Arizona represent the northern extent of a vegetative community also found in parts of New Mexico and Texas, reaching southward through the Sierra Madre Occidental of Mexico. Often referred to as encinal or Madrean evergreen woodlands, these communities occur at elevations of 4,000 to 7,500 ft, and cover approximately 31,500 mi^2 in aggregate. These woodlands are found along drainages, and on rocky slopes with generally thin soils. Depth and type of soil also determine structural development of these woodlands. Average annual precipitation is 15 in.

The two predominant species in southeastern Arizona oak woodlands, Emory oak (*Quercus emoryi*) and Arizona white oak (*Quercus arizonica*), are drought-deciduous and not truly evergreen. Oak regeneration mainly consists of stump sprouts and coppices with low seedling survival under natural conditions (Bennett 1990). Deecken (1988) found that cutting in productive stands resulted in vigorous sprouting leading to canopy closure within seven years.

The study area was located in the San Rafael Valley on the southwestern front of the Huachuca Mountains. Stands of oak woodland harvested in 1972, 1977, 1985, and an undisturbed stand served as sampling areas. Cutting intensities in the harvested areas were 80%, 80%, and 50%, respectively (Bennett 1991). To minimize site differences, areas sampled were between 5,400 and 6,000 ft elevation, on well-drained, south to southwest facing sites, with slopes between 5 and 15%.

Field Methods

Data on structural attributes were collected using the plotless point-quarter method of Cottam and Curtis (1956). Plantlets, either seedlings, root suckers, or sprouts, were excluded from sampling. Twenty sampling points (80 trees) on randomly located transects were collected within each sampling area during the summer of 1991. At each point, the nearest tree (classified as single- or multiple-stemmed) in each quadrant was tallied in terms of species, distance from sampling point, total height, crown depth, diameter, shape (conical, cylindrical, spherical), and density and vertical distribution of crown foliage. Number of stems of multiple-stemmed trees also were recorded. A visual guide was used to estimate crown foliage density (Belanger and Anderson 1989), which was apportioned among 5-ft intervals from 0 to 25 ft.

Analytical Procedures

Number of trees per acre was calculated by a formula presented by Phillips (1959) for the point-quarter method of Cottam and Curtis (1956). Crown volume was estimated from crown shape and average diameter measurements. Foliage volume was the product of crown volume and estimated crown density. This foliage volume estimate is not a direct value of the actual volume of foliage, but an "apparent" value for comparisons. Foliage height diversity (FHD) was calculated using the Shannon-Weiner index:

$$H' = -\Sigma p_i \ln p_i$$

where H' is the diversity index, and p_i is proportion of foliage in the ith horizontal layer.

One-way analysis of variance was performed for each variable. All the F-values were significant ($p < 0.05$), prompting use of Tukey's studentized range test (Zar 1984). Tukey's tests also were repeated for data sets excluding residual trees from each harvest area. Exclusion of residual trees removed effects of differential cutting intensities between areas. Compensation was made for the unbalanced design.

Homogeneity of distributions of tree heights was tested by Chi-squared analysis for pair-wise combinations of locations. Trees were grouped into the following height classes to meet constraints of the test: 0-8, 8.1-10, 10.1-12, 12.1-14, and 14.1-26 ft. Test probabilities were adjusted to account for the multiple comparisons. All tests were carried out at the 95% significance level.

RESULTS AND DISCUSSION

Table 1 summarizes measurements made on randomly selected trees on the study area. The range in tree heights was 3 to 25 ft. Mean foliage volume was lowest on the 1972 harvest area, whereas the 1985 harvest area had a greater mean value of foliage volume than the earlier harvested areas. Mean number of stems per tree was lowest for the undisturbed area and highest for the area harvested in 1985. The greater number of stems per tree on the harvested areas indicates coppicing response from stumps of harvested trees. Tree height and crown depth were different on harvested areas compared to the undisturbed area. The number of stems was different for all comparisons, except that between 1972 and 1977 areas.

When excluding residual trees on the harvested sites, the number of different comparisons was greater than when all trees were included in the analysis (Table 2). Mean height of cut trees in the 1985 area was almost one-half the value obtained when all trees were included. Mean foliage volume also was reduced by excluding residual trees.

The Chi-squared analysis revealed that distributions of tree heights were different for all comparisons, except that between the 1972 and 1977 areas. There were a greater number of trees in the shortest height class for the 1985 area, while the majority of trees on the undisturbed area were in the tallest height class.

Competition between sprouts decreased the mean number of stems with respect to time since harvest, but mean tree height did not change with time since harvest. Both sprout competition and long biological rotation age of oaks likely suppressed height response. Prolific sprouting from oak stumps after harvesting caused a more shrub-like tree form, which shifted canopy profiles downward.

Harvesting intensity is a factor in determining intermediate stages of woodland structural response. Differences in harvesting intensities resulted in few residual trees in the tallest height

Table 1. Mean, standard error, and multiple comparison tests of measurements on trees in a fuelwood management area of the San Rafael Valley in southeastern Arizona.

Variables	1972 Cut Area		1977 Cut Area		1985 Cut Area		Undisturbed Area	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Tree (n = 80)								
Tree Height (ft)	11.3^{A}	0.37	11.1^{A}	0.21	11.2^{A}	0.67	16.1^{B}	0.36
Crown Depth (ft)	11.1^{A}	0.34	10.7^{A}	0.22	10.3^{A}	0.58	14.1^{B}	0.35
Crown Volume (ft³)	$457.^{A}$	84.2	$564.^{AB}$	34.0	$807.^{BC}$	129.	$1050.^{C}$	87.2
Foliage Volume (ft³)	$206.^{A}$	40.1	$273.^{AB}$	18.5	$362.^{BC}$	59.8	$475.^{C}$	39.5
Stems (No./tree)	4.6^{A}	0.46	5.2^{A}	0.40	7.0^{B}	0.79	1.4^{C}	0.09
Stand (n = 20)								
Density (Trees/ac)	$170.^{AB}$	12.6	$211.^{A}$	26.5	$113.^{B}$	17.4	$146.^{AB}$	30.4
Foliage Height Diversity	0.93^{AB}	0.06	0.86^{A}	0.02	1.03^{C}	0.07	1.02^{BC}	0.02

Means with the same letter across rows are not significantly different (Tukey's test, $P < 0.05$)

Table 2. Mean, standard error, and multiple comparison tests of measurements on *cut* trees in a fuelwood management area of the San Rafael Valley in southeastern Arizona.

Variables	1972 Cut Area		1977 Cut Area		1985 Cut Area		Undisturbed Area	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Tree	n = 76		n = 78		n = 47		n = 80	
Tree Height (ft)	10.8^A	0.26	11.0^A	0.21	6.77^B	0.30	16.1^C	0.36
Crown Depth (ft)	10.7^A	0.26	10.7^A	0.23	6.76^B	0.30	14.1^C	0.35
Crown Volume (ft^3)	319.^{A}	30.2	549.^{B}	33.1	148.^{A}	17.5	1050.^{C}	87.2
Foliage Volume (ft^3)	142.^{A}	15.1	266.^{B}	18.1	65.9^A	8.09	475.^{C}	39.5
Stems (No./tree)	4.8^A	0.47	5.3^A	0.41	10.5^B	1.07	1.4^C	0.09

Means with the same letter across rows are not significantly different (Tukey's test, $P < 0.05$).

class for the 1972 area. After 20 years, the resulting structural character still was different from the structural character of the undisturbed area. In contrast, a greater number of taller residuals were observed for the lower intensity harvest on the 1985 area compared to the 1972 area. Nevertheless, this area also had the greatest number of trees in the shortest height class.

The bimodal distribution of tree heights on the 1985 area also produced the highest measured value of foliage height diversity. Foliage height diversity as measured, may not be a "good descriptor" of management impact due to the small degree of resolution. Greater resolution can be afforded by increasing the number of layers considered, because FHD increases as number of layers increases.

Tall trees provide a greater number of habitat niches than short trees. High values of FHD and foliage volume in the 1985 area are indicative of the influence of number of residual mature trees on structural physiognomy and point to management strategies for reduced impact.

CONCLUSIONS

Structural diversity is an important habitat parameter that must be included in management planning. Findings of this study indicated that structural changes persist, as evidenced by differences between the 1972 area and undisturbed area. Differences in structural attributes were found when comparing all harvested areas with the undisturbed area. Therefore, it might be possible to moderate the impact of harvests on woodland structure by adjusting harvest intensity. Removal of older trees must take into account contributions of old, tall trees to woodland structural complexity. Although some changes to woodland structure inevitably will result, multiple-use management objectives for some species of wildlife still might be met. Actual impacts on non-game bird species and other wildlife remain to be evaluated.

LITERATURE CITED

Bahre, C.J. 1991. *A legacy of change.* University of Arizona Press, Tucson, Arizona, 231 pp.

Bahre, C.J., and C.F. Hutchinson. 1985. The impact of historic fuelwood cutting on the semidesert woodlands of southeastern Arizona. Journal of Forest History 29:175-186.

Balda, R.P. 1969. Foliage use by birds of the oak-juniper woodland and ponderosa pine forest in southeastern Arizona. The Condor 71:399-412.

Balda, R.P. 1975. Vegetation structure and breeding bird diversity. *In:* D.R. Smith (tech. coord.). 1975. Proceedings of symposium on management of forest and range habitats for non-game birds. USDA Forest Service General Technical Report WO-1, pp. 59-80.

Belanger, R.P., and R.L. Anderson. 1989. A guide for visually assessing crown densities of loblolly and shortleaf pines. USDA Forest Service Research Note SE-352, 2 pp.

Bennett, D.A. 1990. *First year effects of thinning coppice on Quercus emoryi in southeastern Arizona.* Master Thesis, University of Arizona, Tucson, Arizona, 51 pp.

Bennett, D.A. 1991. Personal communication. USDA Forest Service, Coronado National Forest, Sierra Vista District.

Cottam, G., and J.T. Curtis. 1956. The use of distance measures in phytosociological sampling. Ecology 37:451-460.

Deecken, T. 1988. Wildlife management. In: Ffolliott, P.F. and J.D. Hasbrouck (eds.). 1988. Oak woodland management - proceedings of the workshop held at Sierra Vista, Arizona on April 12-13, School of Renewable Natural Resources, University of Arizona, Tucson, Arizona, pp. 77-78.

Engstrom, R.T., R.L. Crawford, and W.W. Baker. 1984. Breeding bird population in relation to changing forest structure following fire exclusion: a 15 year study. Wilson Bulletin 96:437-450.

Erdelen, M. 1984. Bird communities and vegetation structure: I. Correlations and comparisons of simple and diversity indices. Oecologia 67:277-284.

Karr, J.R., and R.R. Roth. 1971. Vegetation structure and avian diversity in several new world areas. The American Naturalist 105:423-435.

Kirby, K. 1986. Forest and woodland conservation. In: M.B. Usher (ed.). 1986. Wildlife conservation evaluation. Chapman and Hall, London, pp. 202-221.

MacArthur, R.H., and J.W. MacArthur. 1961. On bird species diversity. Ecology 42:594-598.

MacArthur, R., J. MacArthur, and J. Preer. 1962. On bird species diversity II. Prediction of bird census from habitat measurements. American Naturalist 96:167-174.

Magurran, A.E. 1988. *Ecological diversity and its measurement.* Princeton University Press, Princeton, New Jersey. 179 pp.

Mills, G.S., J.B. Dunning, Jr., and J.M. Bates. 1991. The relationship between breeding bird density and vegetation volume. Wilson Bulletin 103:468-479.

Phillips, E.A. 1959. *Methods of vegetation study.* Henry Holt & Co., New York. 107 pp.

Van Dersal, W.R. 1940. Utilization of oaks by birds and mammals. Journal of Wildlife Management 4:404-428.

Zar, J.H. 1984. *Biostatistical analysis.* Prentice-Hall, New Jersey. 718 pp.

Oak Seedling Establishment in California Oak Woodlands[1]

Theodore E. Adams, Jr., Peter B. Sands, William H. Weitkamp, and Neil K. McDougald[2]

Factors contributing to poor establishment of blue oak (*Quercus douglasii*) and valley oak (*Q. lobata*) in California oak woodlands were studied in a series of acorn seeding experiments initiated in 1985. Exclusion of large herbivores permitted examination of herbaceous interference and small mammal and insect depredation. Herbaceous interference was the most important factor. Control improved emergence in nearly 80% of blue oak seedings and in 40% of valley oak seedings. Survival, expressed as a percentage of acorns planted, was significantly improved by elimination of herbs in seedings of both blue oak and valley oak. Limited data suggest that differential survival is maintained over time as overall survival declines. With few exceptions, the addition of screen protection to discourage predation significantly enhanced survival and growth. Shade provided by window screen cages is suspected of making an unmeasured positive contribution. Interaction between herbaceous control and protection appears to develop with time.

INTRODUCTION

Since 1945, the loss of non-commercial oak (*Quercus* spp.) woodland in California is estimated to be in excess of 400 thousand hectares or 16% of the 3 million hectares total (Bolsinger 1988). These losses resulted from rangeland clearing, road and freeway construction, and residential-commercial development. Limited data suggest the latter cause surpassed rangeland clearing by 1973 as the dominant source of loss.

Loss of oaks is compounded by relatively sparse recruitment in blue oak (*Q. douglasii*) stands, occupying about 1.2 million hectares or 40% of the oak woodlands, and almost nonexistent recruitment in valley oak (*Q. lobata*) stands (Bolsinger 1988). Unsuccessful blue and valley oak recruitment results from mortality at the seedling and sapling stages rather than from inadequate germination and seedling emergence (Griffin 1971). Development of restocking techniques and evaluation of their relative efficacy are needed to preserve the community and management options for oak woodlands. This study examined the influence of herbaceous competition and small mammal and insect herbivory on emergence, survival, and growth of seedlings; and included an evaluation of selected techniques for reducing negative impacts.

PROCEDURES

Over a period of 5 years (1985-1989), blue and valley oak acorns were collected each year from trees in late summer through early fall and seeded in oak-woodland field plots during the November-December period in 6 California counties (fig. 1). Not all locations were planted each year because local acorn production was irregular and sometimes inadequate for full execution of the experimental treatments. All work was conducted in open areas on oak sites away from canopy effects and within deer-proof enclosures to exclude browsing of seedlings by large herbivores, an acknowledged problem (Longhurst et al. 1979, Menke and Fry 1980)

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[1] Poster presented at the Symposium on Ecology and Management of Oak and Associated Woodlands: Perspectives in the Southwestern United States and Northern Mexico, Sierra Vista, Arizona, April 27-30, 1992.

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Oak woodland sites in California's Mediterranean-like climate have understories dominated by annual grasses. Throughout the study area, annuals continue to grow until all available soil water is exhausted. A discussion of the ecology and composition of California annual grasslands is presented by Heady (1977).

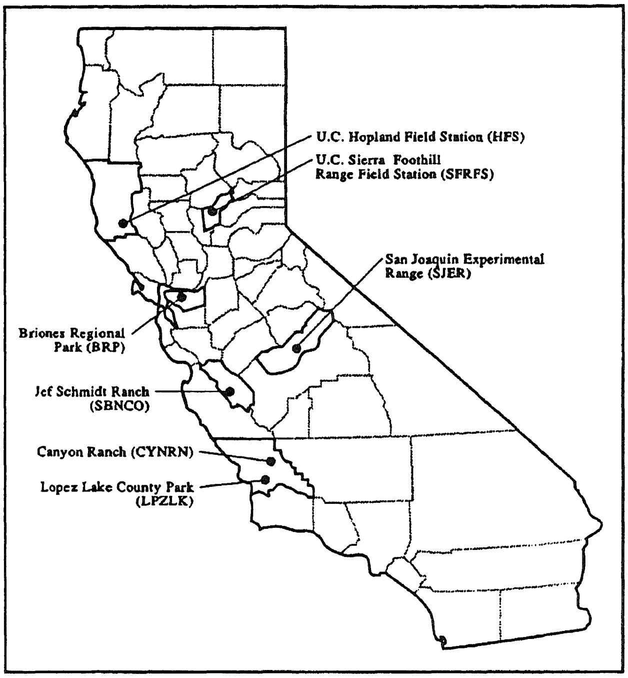
U.C. Hopland Field Station (HFS)
U.C. Sierra Foothill Range Field Station (SFRFS)
San Joaquin Experimental Range (SJER)
Briones Regional Park (BRP)
Jef Schmidt Ranch (SBNCO)
Canyon Ranch (CYNRN)
Lopez Lake County Park (LPZLK)

Figure 1. Location of 7 oak woodland study sites in 6 counties

At each site, treatments were the factorial set of 2 levels of herbaceous plants (none and the naturally occurring vegetation) and 2 levels of protection against small mammal and insect damage (screens and no screens). The experimental design was a randomized complete block with the 2 levels of herbaceous plant control as main plots and screen protection applied as a split on main plots.

Each main plot treatment consisted of 100 acorns planted in four rows of 25 each with 30 cm between acorns and rows. Planting depth was 5 cm, and each 100 acorns represented 1 replication.

Emergents in each main plot were randomly split into 2 groups, protected and unprotected, with protection provided by window screen cages (closed cylinders 15 cm in diameter and approximately 40 cm high) or 14-strand rigid plastic seedling protectors (screens) 5 cm in diameter and 30 cm high. The large mesh plastic screens were substituted for window screen cages when the threat from grasshoppers (*Melanoplus devastator*) was minimal.

Observations evaluated by analysis of variance (ANOVA) included emergence, survival measured in the spring of each growing season, and height of plants each fall. Data were pooled over locations in the analyses. When measuring height, the longest stem was used if branching occurred. Unless otherwise noted, significant differences are reported at the 95 percent level.

RESULTS AND DISCUSSION

Overall emergence of 14 blue and 10 valley oak seedings was improved ($P \leq 0.05$) through herb control. Average emergence of blue oak with control was 45%. Without control, it was 29%. The respective values for valley oak were 61% and 46%.

Information on survival for 3 growing seasons with and without herbaceous plant control and screen protection was available for 3 blue oak seedings (fig. 2) and 3 valley oak seedings (fig. 3). Analysis of these data showed that both control and protection influenced ($P \leq 0.01$) survival and that interaction ($P \leq 0.01$) between main factors developed over time.

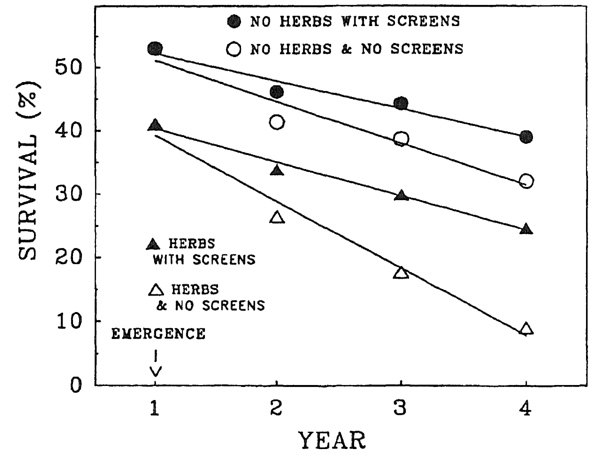

Figure 2. Three-season survival (% of acorns seeded) of blue oak growing with and without control of herbaceous plants and with and without screen protection in 3 seedings: CYNRN 1987, HFS 1986, SFRFS 1987. Observations made in spring after bud break.

In blue oak, declines in survival with screen protection were not different, but after 3 seasons, nearly 60% greater survival occurred among seedlings growing with both control and protection. Regression equations for survival in the 2 levels of weed control, each protected, are $Y = 56.3 - 4.32X$ ($R^2 = 0.96$) and $Y = 43.6 - 5.06X$ ($R^2 = 0.85$). Over time, mortality among unprotected seedlings increased at a greater ($P \leq 0.01$) but proportional rate. Among seedlings growing without either protection or herbaceous plant control, loss was more rapid ($P \leq 0.01$) than among unprotected seedlings growing with control. This difference was proportional, and after 3 seasons, 3.5 times more unprotected seedlings growing with herbaceous plant control were alive. Regression equations for survival of unprotected seedlings growing with and without herb control are, respectively, $Y = 55.4 - 6.30X$ ($R^2 = 0.84$) and $Y = 49.6 - 10.4X$ ($R^2 = 0.98$). The slopes of the lines represented by these equations are different ($P \leq 0.001$).

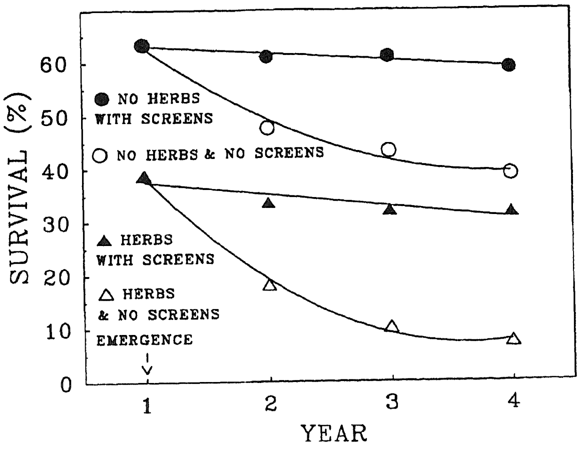

Figure 3. Three-season survival (% of acorns seeded) of valley oak growing with and without control of herbaceous plants and with and without screen protection in 3 seedings: BRP 1987; HFS 1986, 1987. Observations made in spring after bud break.

After 3 seasons without control of herbs, 37% as many blue oak seedlings were alive in the absence of protection as were alive with protection. With herb control, 82% as many unprotected seedlings were alive after 3 seasons as were alive with protection. The best treatment, herb control with screens, contained more than 4 times as many seedlings as the worst treatment, no herb control and no screens.

As in blue oak, declines in survival among valley oak seedlings growing with screen protection were not different. However, after 3 seasons, the combination of herb control and protection had encouraged 85% more survival compared with no herb control and protection. Regression equations for survival of protected seedlings growing with and without herb control are, respectively, $Y = 64.4 - 1.35X$ ($R^2 = 0.90$) and $Y = 39.8 - 2.29X$ ($R^2 = 0.82$). Over time, mortality among unprotected seedlings followed the pattern observed in blue oak; it increased at a greater ($P \leq 0.01$) rate. Overall, this rate was nonlinear, but after the first season, it was proportional. The second order regression equations for unprotected seedling survival with and without herb control are, respectively, $Y = 81.7 - 21.8X + 2.80X^2$ ($R^2 = 0.98$) and $Y = 66.6 - 32.6X + 4.48X^2$ ($R^2 = 0.99$). Rates of decline in survival between unprotected seedlings in the 2 levels of herb control were different ($P \leq 0.01$), and this difference was proportional. After 3 seasons, 5 times more unprotected seedlings growing with herbaceous plant control were alive.

In the absence of screen protection, the increase in valley oak mortality was greatest for seedlings growing without herb control; 23% as many seedlings were alive after 3 seasons as were alive in the treatment with protection. With herb control, the difference was smaller; in the absence of protection, 66% as many seedlings were alive after 3 seasons. As in blue oak, the best treatment after 3 seasons represented herb control combined with screen protection. There were nearly 8 times more seedlings in this treatment than were found in the worst treatment, no control with no protection.

Average height of seedlings developing in 5 blue and 4 valley oak plantings made in 3 consecutive years, 1986-88, were compared over all treatment combinations (table 1). Survival in the absence of herb control and screen protection produced too few plants for measurement; but when these treatments were combined, height of seedlings was 50-60% greater than in the next best treatment combination, no herb control with screens. The shortest plants measured, those with herb control but no screens, were less than half as tall as those growing with both control and protection.

Only 46% of incident sunlight is transmitted through window screen cages (measured in $uE\ m^{-2}\ s^{-1}$ by a quantum sensor). The shade produced probably contributed to the differential in survival and height between protected and unprotected plants. Crow (1988) observed that seedlings of northern hardwoods, including those of red oak (*Q. rubra*), in the central United States generally benefit from shade because it reduces water stress by moderating temperatures and evapotranspiration. Total shoot weight of 5-to-7-year-old seedlings of 9 northern hardwoods grown in full sunlight and 45% of this did not differ significantly, but all grew significantly taller at the lower intensity (Logan 1965, 1966, 1973). In our studies we believe the screens provided an element of protection against excessive transpiration such as that found beneath tree canopies and in other environments favorable to early growth of seedlings. However, the shade factor could not be separated from the effect of protection.

Table 1. Average effects of herb control and screen protection on 1991 seedling height (cm) in 5 seedings of blue oak (Hopland Field Station [HFS] and Sierra Foothill Range Field Station [SFRFS], 1986; Canyon Ranch [CYNRN] and SFRFS, 1987; HFS, 1988) and 4 of valley oak (HFS, 1986; Briones Regional Park [BRP] and HFS, 1987; HFS, 1988).

		Seedling Height (cm)[1]	
Species	Screen Protection	Herbs	No Herbs
Blue Oak	No	__[2]	20C
	Yes	23B	48A
Valley Oak	No	__	23C
	Yes	30B	49A

[1] Values for each species not followed by the same letter are different ($P \leq 0.01$) by LSD Separation.

[2] Absence of values reflects inadequate survival for reliable estimates.

CONCLUSIONS

Control of herbs improves emergence and survival of seedlings developing from planted blue and valley oak acorns. Limited data on long-term survival suggests seedling mortality over time is reduced by herb control.

Screens protected seedlings against insects and small mammals and significantly improved survival and growth of both oaks at most locations. Window screen cages provided the best protection against grasshoppers, the principal insect herbivore on seedlings. Screens are recommended for all plantings in openings away from tree canopy.

Window screen cages not only protect seedlings from predation but modify the seedling microenvironment. They provide shade, the beneficial effects of which we could not separate from protection.

We suspect the negative effects of herbaceous interference and predation may be modified by using livestock for biological control of phytomass in carefully managed systems that would limit damage to oak seedlings. Such systems will reduce herbaceous cover and may effectively modify habitat, thus reducing potential predation. Such a strategy needs evaluation.

LITERATURE CITED

Bolsinger, C.L. 1988. The hardwoods of California timberlands, woodlands and savannas, USDA, Forest Service Resource Bull. PNW RB-148.

Griffin, J.R. 1971. Oak regeneration in the upper Carmel Valley, California. Ecol. 52:862-868.

Logan, K.T. 1965. Growth of tree seedlings as affected by light intensity. I. White birch, yellow birch, sugar maple and silver maple. Can. Dep. Forest Pub. No. 1121.

Logan, K.T. 1966. Growth of tree seedlings as affected by light intensity. III. Basswood and white elm. Can. Dep. Forest. Pub. No. 1176.

Logan, K.T. 1973. Growth of tree seedlings as affected by light intensity. V. White ash, beech, eastern hemlock, and general conclusions. Can. Dep. of the Environ., Forest Service Pub. No. 1323.

Longhurst, W.M., G.E. Connolly, B.M. Browning, and E.O. Garton. 1979. Food interrelationships of deer and sheep in parts of Mendocino and Lake Counties. Hilgardia 47:191-247.

Menke, J.W., and M.E. Fry. 1980 Livestock utilization of California's oak woodlands, p. 297-305. In: Proc. Symposium on the Ecology, Management, and Utilization of California Oaks (tech. coord. T.R. Plumb) USDA, Forest Service General Tech. Rep. PSW-44.

Structure of a Variable-Density Yield Table for Emory Oak[1]

Wm. Patrick Fowler and Peter F. Ffolliott[2]

Abstract.–A variable-density yield table developed for use in Emory oak stands of southeastern Arizona has application as a growth and yield model. Inputs to the model include age, site index, and basal area, variables obtained easily from inventory data. Further testing of the variable-density yield table is necessary, however, before it is applied more generally.

Until recently, there has been little interest in developing techniques to estimate growth and yield of non-commercial woodlands in the southwestern United States and northern Mexico. However, increased use of oak woodlands for fuelwood and fenceposts, livestock production, watershed protection, wildlife habitats, and recreation requires knowledge of growth and yield relationships to place woodlands under sustainable development and conservation. Quantification of growth and yield enables a manager to determine the time at which a woodland should be harvested, and the intensities of silvicultural treatments necessary to maintain woodlands in optimal growing conditions.

DESCRIPTION OF STUDY

The purpose of this study was to develop a growth and yield model for application in oak woodlands. A yield table approach to modeling was selected for this development. Yield tables present estimates of volume for even-aged stands from knowledge of age, site index, and stand density (Avery and Burkhart 1983, Husch et al. 1982). Yield tables have been used to estimate growth and yield of forests and woodlands in the United States since the early 1900s (Curtis 1972).

There are three types of yield tables, normal, empirical, and variable-density. Normal and empirical yield tables are based upon concepts of "normally stock" stands and average local stocking of stands, respectively. It is frequent that these standards poorly define stocking conditions for irregularly stocked stands and, therefore, arbitrary adjustments are required in estimating volume (Clutter et al. 1983). To overcome this problem, a measurement of stand density is included as an independent variable in variable-density yield tables. Independent variables in variable-density yield tables are age (an indicator of the stage of stand development), site index (a measure that integrates factors that affect growth of trees on a site), and a measure of stand density.

Study Area

Source data for development of the growth and yield model were collected on the Coronado National Forest in southeastern Arizona. Emory oak (*Quercus emoryi*) is the predominate species, with silverleaf (*Q. hvpolevoides*), Arizona white (*Q. arizonica*), Mexican blue (*Q. oblonqifolia*), netleaf (*Q. ruqosa*), gray (*Q. qrisea*), and shrub live (*Q. turbinella*) oaks intermixed. Sample measurements were collected only on Emory oak trees, however.

Emory oak is found at elevations from 5,000 to 6,550 feet, on undulating topography of diverse aspects and topography. Soils are formed in old alluvium from mixed igneous and sedimentary rocks and, in general, more than 60 inches deep. Annual precipitation averages 15 to 20 inches. The study area is located in the *Quercus emoryi / Bouteloua curtipendula* habitat.

Field Procedures

Source data were obtained on 84 temporarily located 1/10-acre sample plots randomly distributed in two strata. Fifty-one plots were located in uncut oak woodland stands and 33 plots in stands which had experienced partial fuelwood harvesting. Individual tree measurements included dbh, total height, and crown position (dominant, co-dominant, intermediate, or suppressed). When found on plot, a dominant or co-dominant tree was cored with an increment borer to estimate age. If such a tree was not found, a dominant or co-dominant tree immediately off the plot was cored. Average age of trees on each sample plot was determined from relations of dbh and total height to age, or knowledge of prior fuelwood harvesting.

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Analytical Techniques

Yield tables are tabular presentations of volume of even-aged stands, categorized by tree species and age, site, and density classes (Husch et al. 1982). With use of computers, however, yield tables also can be presented as a set of equations, as they are in this study. This approach required development of appropriate variables, as described below.

After collecting source data, volume and basal area (the latter representing a measure of stand density) of Emory oak trees on each sample plot were calculated. Volume in cubic feet was estimated from equations presented by Chojnacky (1988). Because of frequently encountered multi-stemmed nature of Emory oak, sample trees were differentiated into single-stemmed and multi-stemmed classes, and the appropriate volume equations employed. Basal area was selected as the measure of stand density because it can be converted easily to other expressions of stand density. Furthermore, a number of multiple-use relationships in oak woodlands have been developed with basal area as an independent variable. Site index of the sample plots also was determined (Callison 1989).

Initial statistical analysis indicated that data sets from uncut and partially harvested sample plots were not different in terms of the variables studied and, therefore, were pooled for subsequent analysis. A multiple regression approach to development of variable-density yield tables has been used in similar studies (Avery and Burkhart 1983, Clutter et al. 1983, Husch et al. 1982), with the model initially proposed by Schumacher (1939) most commonly used, as it was in this study. A stepwise multiple regression analysis (Sokal and Rohlf 1981) was used to relate volume to age, site index, and basal area. Variable transformations were based on knowledge of processes being modeled and statistical fit of data points (Little and Hills 1978).

VARIABLE-DENSITY YIELD TABLE

The variable-density yield table, also is a growth and yield model for Emory oak, is represented by:

$$\ln(V)=1.25-8.83(A^{-1})+0.565(lnSI)+1.01(lnBA) \quad (1)$$

$$S_{y.x} = 0.186$$
$$r^2 = 0.951$$

where V is volume in cubic feet, A is age of stand in years, SI is site index, and BA is basal area in square feet per acre.

Equation (1) facilitates estimation of current yield by solving a variable-density equation obtained for current stand conditions. Future yield is estimated by making appropriate adjustments in age and basal area values. Age is a straightforward adjustment in current age to reflect future age. However, basal area adjustment is more complex. Not only does volume change with time, but basal area also changes with time. Therefore, a set of equations to adjust basal area values to estimate future yields was developed.

In developing these equations, data were grouped into three site index classes and, within each class, relationship of basal area to age determined. Site Class I included site index values greater than 17, Site Class II site index values between 13 and 17, and Site Class III site index values less than 13. Second-degree polynomials defining these relationships were differentiated to describe changes in basal area with respect to age. Basal area values are adjusted in the growth and yield model by using one of the following equations:

Site Class I

$$\frac{dBA}{dA}=1.85-0.0318(A) \quad (2)$$

Site Class II

$$\frac{dBA}{dA}=1.55-0.0276(A) \quad (3)$$

Site Class III

$$\frac{dBA}{dA}=0.155-0.023(A) \quad (4)$$

To solve for future yield, the adjusted future basal area value is determined by summing estimated annual changes in basal area from current age to future age for the appropriate site class. Total change in basal area is added to the current basal area value to obtain an estimate of basal area in the future. The adjusted basal area value, future age, and site index value, which remains unchanged because it is a characteristic of the site, are inputs to equation (1) to estimate future yield. Future yield estimates, therefore, are based on current stand conditions adjusted to reflect future stand conditions. Change in yield between current and future stand conditions is growth.

APPLICATION

Application of the growth and yield model in estimating current yield, future yield, and growth is illustrated for an Emory oak stand not included in the study. From independent inventory data, it was determined that the stand is 25 years old, site index is 15, and current basal area is 15.9 square feet per acre. Current yield, estimated by solving equation (1) in terms of these input variables, is 185 ± 1.48 cubic feet per acre.

Future yield at age 40, for example, is estimated by changing the age variable accordingly, using the site index value of 15, and adjusting the basal area value by solving equation (3), which represents Site Class II, for ages 26 through 40 and summing the annual estimates of change. These variables are used to solve equation (1) once again, this time to estimate future yield. In this example, future yield is 340.5 ± 1.46 cubic feet per acre.

Growth is expressed on an annual basis by dividing total growth by number of years in the growth period, in this case 15 years. Annual growth in this example is estimated to be 10.4 ± 2.3 cubic feet per acre.

CONCLUSIONS

The estimate of current yield agreed with estimates of current yield obtained from Forest Inventory and Analysis (FIA) inventory data for oak woodlands in Arizona (Conner et.al. 1990). Estimates of future yield and growth were similar to those obtain independently from a simulation model based on a stand projection method (Ffolliott et al. 1988). It was concluded, therefore, that the variable-density yield table is applicable to Emory oak stands in southeastern Arizona. Estimations of growth and yield for a wider range of stand conditions and longer periods of time, for example, over rotational cycles, must be validated, however.

LITERATURE CITED

Avery, T. E., and H. E. Burkhart. 1983. Forest measurements. 331p McGraw-Hill Book Company, New York.

Callison, J. C. 1989. Site quality indices in oak woodlands. Ph.D. 38p. Dissertation, School of Renewable Natural Resources, College of Agriculture, University of Arizona, Tucson, Arizona.

Chojnacky, D. C. 1988. Juniper, pinyon, oak, and mesquite volume equations for Arizona. USDA Forest Service Research Paper INT-391, 11 p. Intermountain Research Station, Ogden, Utah.

Clutter, J. L., J. C. Fortson, L. V. Pienaar, G. H. Brister, and R. L. Bailey. 1983. Timber management: A quantitative approach. 333 p. John Wiley & Sons, Inc., New York.

Conner, R.C., J.D. Born, A.W. Green, and R.A. O'Brien. 1990. Forest Resources of Arizona. USDA Forest Service Resource Bulletin INT-69, 92 p. Intermountain Research Station, Ogden, Utah.

Curtis, R. O. 1972. Yield tables past and present. Journal of Forestry 70:28-32.

Ffolliott, P. F., W. O. Rasmussen, and D. P. Guertin. 1988. STAND: An interactive model to simulate the growth and yield of woodlands in the Southwest. p. 968-975. In: Ek, A. R., 5. R. Shifley, and T. E. Burk. (eds.) Forest growth modelling and prediction: Proceedings of the IUFRO conference. USDA Forest Service General Technical Report NC-120, 1,149 p. North Central Forest Experiment Station, St. Paul, Minnesota.

Husch, B., C. I. Miller, and T. Beers. 1982. Forest mensuration. 402 p. John Wiley & Sons, Inc., New York.

Little, T. M., and F. J. Hills. 1978. Agricultural experimentation design and analysis. 350 p. John Wiley & Sons, Inc., New York.

Schumacher, F. X. 1939. A new growth curve and its application to timber yield studies. Journal of Forestry 37:819-820.

Sokal, R. R., and F. J. Rohlf. 1981. Biometry. 859 p. W. H. Freeman and Company, San Francisco.

Soil Temperatures Related to Prescribed Burning in Ponderosa Pine Stands in Yosemite Valley that Include California Black Oak[1]

Stephen S. Sackett, Sally M. Haase, Gloria M. Burke[2]

Abstract.–Prescribed burning has been actively carried out in Yosemite National Park since the early 1970's. In the past 2 years an effort has been made to identify an unseen effect of burning, namely soil temperatures. Fires in both giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz) and mixed-conifer stands and ponderosa pine stands (*Pinus ponderosa* Dougl. ex Laws.) have been documented thoroughly. In two of the ponderosa pine stands burned, California black oak trees (*Quercus kelloggii* Newb.) were present. Soil temperatures measured near the bases of these two trees reflect quite different heat fluxes. Heat did not penetrate through the soil where the black oak tree fuels dominated the microsite. In another case, the oak tree was smaller, and the litter fuels from the surrounding pines dominated composition of the forest floor. Heating on that site was substantially greater and at much lower depths. A preponderance of oak leaves in the total makeup of the forest floor appears to reduce the combustibility of the forest floor, hence the resulting decreased soil heating.

INTRODUCTION

Since European settlement of much of the West in the late 1800's and the development of fire exclusion policies in the early 1900's, major changes in the way fire interacts in many ecosystems have occurred. Fuel buildup and a flush of young trees cause hazardous conditions to exist where once natural fires kept these elements in check.

For over 20 years now, prescribed fire and prescribed natural fire management programs have been part of the ponderosa pine and sequoia-mixed conifer ecosystems in Sequoia, Kings Canyon, and Yosemite National Parks (Kilgore 1981, Bancroft et al. 1985, Parsons and Nichols 1986).

Many questions have surfaced regarding both objectives and methods as a result of the National Park Service's (NPS) prescribed fire program. The general goal in the NPS burning program is "to maintain or restore natural fire regimes to the maximum extent possible so that ecosystems can function essentially unimpaired by human interference." In 1986 a panel was assembled "to evaluate the effectiveness of the NPS fire management program in the sequoia-mixed conifer forests of the Sierra Nevada" (Christensen et al. 1987, Parsons 1990). Different areas in the Parks have been burned almost every year to reduce heavy surface fuels and to reintroduce fire to its natural role in these ecosystems. Fire history data in a number of forms indicate the existence of periodic fires in all temporal phases of managed ecosystems (Kilgore and Taylor 1979, Tweed 1987). Reinitiating of the ecological fire process is deemed necessary for the long-term maintenance of such ecosystems (van Wagtendonk 1983, Parsons et al. 1986)

A number of recommendations were made as a result of the panel's review of the National Park's burning programs in the Sierra Nevada (Parsons 1990). One was to continue and expand research on the many aspects of fire effects on the giant sequoia-mixed conifer ecosystem. One question raised relates to the use of fire for restoration of an ecosystem when fuels surrounding the trees are perceived to be "unnaturally" or unusually heavy because of the long-term exclusion of fire. The specific concern is that temperatures might be elevated in the soil and on the tree boles sufficiently to cause damage to root and cambial tissue.

Our research in both Parks centers on documenting temperatures in the soil rooting zone and in tree cambiums during prescribed fires in black oak, giant sequoia, sugar pine, and ponderosa pine stands. Soil and cambium temperatures have been studied as well in ponderosa pine stands in Arizona[3] using a thermocouple temperature-monitoring system developed for that specific purpose (Sackett and Haase, in press). Prescribed fires in the Parks have been studied since

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[3] *Unpublished data on file, Pacific Southwest Research Station, Riverside, California.*

1987. Black oaks occur primarily in the ponderosa pine and sugar pine stands.

METHODS

Before each burn, six soil temperature monitoring probes were installed at depths ranging from the soil and duff interface to 22 inches below the soil surface in sequoia-mixed conifer stands and 12 to 18 inches in ponderosa pine stands. Six to ten sites were established on each burn at locations that represent the different depths of forest floor in which the fire is burning.

As the forest floor is ignited, flaming combustion skims off the top litter layer of newly accumulated organic material. As flaming combustion diminishes on the forest floor, glowing combustion continues in the older, more tightly compacted duff layers. An ash layer forms as combustion progresses and acts as an insulation barrier to heat escape. Heat penetration in the soil continues during the glowing combustion phase, often for days.

On sites where soil temperature is monitored, consumption of forest floor fuels has almost always been complete regardless of moisture contents of duff. If environmental conditions allow forest floor material to ignite, all the material will be consumed over the course of the fire in sequoia-mixed conifer stands. The same has been shown to be true where forest floor duff layers are heavy in ponderosa pine stands.

Probes that monitor cambium temperature were also installed in giant sequoia, sugar pine, and ponderosa pine trees during selected Park burns. Probes are installed so that the measuring tip is located in the tree cambium at a point half the distance between the soil and the top of the forest floor. Installation of probes is quite easy in pine species, but the extremely thick bark of giant sequoia makes temperature sensing very difficult.

RESULTS

Substantial soil and cambium heating has been documented in various ecosystems with heavy forest floor loadings caused by fire exclusion. In heavy forest floor sequoia-mixed conifer stands (average 70 tons/acre), temperatures average 134°F at 8 inches below the soil surface. Ponderosa pine sites in the Yosemite Valley have been burned where forest floor loadings range from 22 to 70 tons per acre. Under those conditions, soil temperatures average 106 °F at 8-10 inches. Soil temperature approached 96 °F at 14 inches in one case.

In two of the Yosemite ponderosa pine stands California black oaks were present. Both sites were in the Yosemite Valley along the Merced River. In the first stand, a large (39.9 inch d.b.h.), full-crowned oak was growing in a clump of large (39.5 inch d.b.h.) yellow pines, and mixed with incense-cedar (*Libocedrus decurrens* Torr.). Because of the full crown on the oak, the forest floor composition was dominated by oak leaves. In the second stand, a smaller oak tree (9.1 inch d.b.h.), with a slope to the bole, caused the crown to extend away from the base of the tree. The site was dominated by large (31.6 inch d.b.h.) ponderosa pines, and the forest floor around the oak was hence dominated by pine needle litter.

Temperature traces from the two sites were drastically different from one another, presumably because of the forest floor composition. The preponderance of oak leaves on the first site did not allow the fire to penetrate past the upper, loosely held litter layer. Very little duff was consumed around the oak (13 tons per acre), whereas 15 feet away, the entire forest floor (58 tons per acre) was consumed where the composition was totally ponderosa pine needles, twigs, and bark. Temperature 2 inches below the soil surface near the oak tree only reached 65 °F (fig. 1), whereas surface temperature near the pines exceeded 162 °F. The deepest point at which there was a temperature flux (62 °F) was at 8 inches near the oak. Temperatures elevated to 111 °F at 8 inches below the soil surface near the pines.

At the second site where oak leaves were not a large component in the forest floor near the tree base, soil temperatures elevated to 115 °F at depths of 6 inches and to 98 °F at 8 inches below the soil surface (fig. 2). Sixty-one tons per acre of forest floor fuel were completely consumed at 18 inches from the bole where temperatures were measured, and consumption was complete immediately around the bole.

CONCLUSIONS

It appears from the limited amount of data, yet thorough visual examination, that a preponderance of oak leaves in the total makeup of the fuel reduces

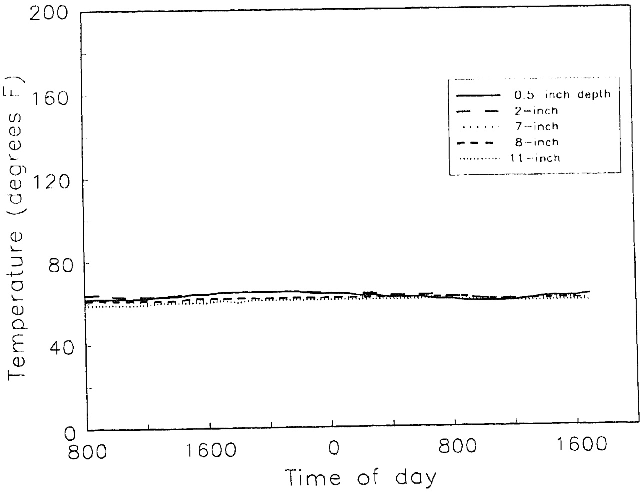

Figure 1. Temperatures at five depths below the soil surface, over 36 hours, in ponderosa pine stands in Yosemite National Park, California.

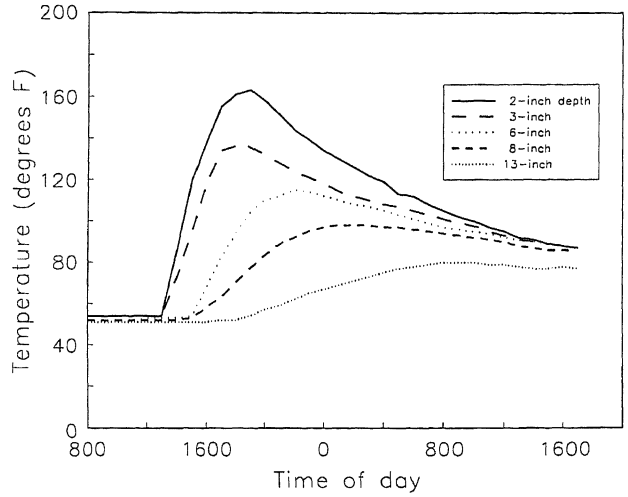

Figure 2. Soil temperatures, over a 36-hour period, during a prescribed burn in a ponderosa pine stand at Yosemite National Park, California.

the combustibility of the forest floor, hence reducing soil heating. The reduced combustibility also keeps heating away from the tree boles.

Additional work is needed to quantify the effects of prescribed burning on California black oak growing in association with ponderosa pine.

LITERATURE CITED

Bancroft, L.T., T. Nichols, D. Parsons, D. Graber, B. Evison, and J. van Wagtendonk. 1985. Evolution of the natural fire management program at Sequoia and Kings Canyon National Parks. *In*: Proceedings Symposium and Workshop on Wilderness. Gen. Tech. Rep. INT-182. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station.

Christensen, N., L. Cotton, T. Harvey, R. Martin, J. McBride, P. Rundel, and R. Wakimoto. 1987. Review of fire management program for sequoia-mixed conifer forests of Yosemite, Sequoia and Kings Canyon National Parks. Final Report. 37 pp.

Kilgore, B. 1981. Fire in ecosystem distribution and structure: Western forests and scrublands. *In*: Proceedings of the Conference: Fire Regimes and Ecosystem Properties, Section 1, Ecosystem distribution and structure through space and time. Gen. Tech. Rep. WO-26. U.S. Department of Agriculture, Forest Service. p. 58-89.

Kilgore, B. and D. Taylor. 1979. Fire history of a sequoia-mixed conifer forest. 60(1):129-142.

Parsons, D. 1990. The giant sequoia fire controversy: The role of science in natural ecosystem management. *In*: Proceedings of the Third Biennial Conference on Research in California's National Parks, Davis, California, University of California, 1988 September 13-15. Eds. Charles van Riper III, Thomas J. Stohlgren, Stephen D. Veirs, Jr., and Silvia Castillo Hillyer. Transactions and Proceedings Series No. 8. U.S. Department of Interior, National Park Service.

Parsons, D., D. Graber, J. Agee, and J. van Wagtendonk. 1986. Natural fire management in the National Parks. Environmental Management 10(1):21-24.

Parsons, D. and T. Nichols. 1986. Management of giant sequoia in the National Parks of the Sierra Nevada, California. In: Workshop on Management of Giant Sequoia, 1985 May 24-25, Reedley, California. Gen. Tech. Rep. PSW-95, U.S. Department of Agriculture, Forest Service.

Sackett, S.S. and S. Haase. Measuring soil and tree temperatures during prescribed burning. Gen Tech. Rep. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. (In press)

Tweed, W. 1987. Born of fire: Prescribed burns will be the salvation of sequoia groves. National Parks. January - February. P. 23-27, and 45.

van Wagtendonk, J. W. 1983. Fire suppression effects on fuels and succession in short-fire - internal wilderness ecosystems. *In*: Proceedings of Wilderness Fire Symposium, Missoula, Montana, 1983 November 15-18.

Specific Gravity and Estimated Physical Properties of Emory Oak in Southeastern Arizona[1]

John K. Maingi and Peter F. Ffolliott[2]

Abstract.–Average specific gravity of Emory oak (*Quercus emoryi* Torr.) estimated from 115 increment cores was 0.567 ± 0.011. Increment core specific gravity was a predictor of average tree specific gravity. Of the tree and stand variables tested, only diameter breast height and diameter root collar were correlated with increment core specific gravity. Estimated physical properties of Emory oak were lower than those reported for Gambel oak (*Quercus gambelii* Nutt.).

INTRODUCTION

Appraising suitability of a tree species for primary wood products requires knowledge of physical characteristics of the wood itself. Specific gravity, one of the most important physical properties that determines the value of a species for potential product utility, can be used to determine the weight of dry fiber and, therefore, plays a major role in determining the use of wood for pulp and fuel. It is the best single index of wood strength, stiffness, shock resistance, and charcoal or fiber recovery. Variabilities expected in these physical properties can be inferred from specific gravity variation. Consequently, a measure of specific gravity for a tree species is desirable. A study to determine specific gravity of Emory oak is described in this paper.

DESCRIPTION OF STUDY

Objectives of the study were to determine the specific gravity of Emory oak from a sample of increment cores; develop a relationship between average tree specific gravity and specific gravity estimated from increment cores; ascertain whether specific gravity estimated from increment cores varies with tree and stand variables; and estimate physical properties of the tree species from knowledge of specific gravity.

Study Area

This study was carried out in oak woodlands in San Rafael Valley on the southwestern slopes of the Huachuca Mountains. Soils on the area are predominantly a Casto-Martinez-Canelo soil association, generally occurring on dissected fans and piedmonts. These soils, more than 60 inches deep, were formed from mixed sedimentary rock on old alluviums (Richardson et al 1979). Annual precipitation ranges from 12 to 18 inches with approximately 65 percent of the moisture falling in the summer.

Field Methods

Increment cores were collected from 115 trees on five sites exhibiting a variety of stand and topographical situations. Sample trees, free from morphological flaws, were selected randomly on each site. Each tree formed the center of a 0.2- acre plot. Individual tree characteristics measured were diameter outside bark at root collar (drc), diameter at breast height (dbh), proportion of the stem occupied by the crown, and crown vigor. Plot measurements were basal area per acre, slope percent, and aspect.

An increment borer was used to extract cores at breast height from each sample tree. The cores were taken to the Tree Ring Laboratory, University of Arizona, for analysis. In addition, six sample trees ranging from 4 to 9 inches in dbh were felled and disks 2 inches thick sawed-off at three different tree heights. These disks also were taken to the laboratory for determination of specific gravity.

Laboratory Methods

In the laboratory, each increment core was soaked in distilled water overnight and its green volume determined by the water immersion. The cores then were oven-dried at 105°C until there was no change in weight, and the weight measured to the nearest 0.001 gram. Specific gravity of each core was determined by dividing oven-dry weight by green volume. After removal of bark, disk specific gravity values were determined as described above.

Analytical Procedures

Mean and standard error of the 115 estimates of increment core specific gravity were determined. Average tree specific gravity was estimated by summing weighted values of disk specific gravity collected at each tree height.(Weighting was based on proportion of volume of the bolt from which each disk was cut.) Simple regression analysis was used to determine whether average tree specific gravity could be predicted from increment core specific gravity. Multiple regression analysis was used to describe relationships between increment core specific gravity and individual tree and stand variables (SAS Institute Inc. 1989). All tests were evaluated at the 5 percent level of significance.

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[1] *Paper presented at the symposium on the Ecology and Management of Oak and Associated Woodlands: Perspectives in the Southwestern United States and Northern Mexico. [Sierra Vista, Arizona, April 27-30, 1992]*

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Selected physical properties of Emory oak were estimated through solutions of empirical equations based on knowledge of specific gravity (Markwardt and Wilson 1935, USDA Forest Service 1956).

RESULTS AND DISCUSSION

Specific Gravity

Average specific gravity of Emory oak as estimated from increment cores was 0.567 ± 0.011. This value is less than the value of 0.634 ± 0.010 reported for Gambel oak in Northern Arizona (Barger and Ffolliott 1964). The reason for this difference is unknown.

The regression equation for predicting average tree specific gravity from increment core specific gravity was, $Y = 0.521 + 0.376X$, where Y = tree specific gravity and X = increment core specific gravity. The coefficient of determination for this equation was 0.660.

Regression equations accounting for significant variability in increment core specific gravity had transformations of dbh and drc as independent variables. The equations were, $Y = 0.526 + 2.10(1/X_1)$ and $Y = 0.524 + 4.055(1/X_2)$, respectively, where Y = increment core specific gravity, X_1 = square of dbh, and X_2 = square of drc. Coefficients of determination for the regression equations were 0.182 and 0.171, respectively, indicating relatively low predictive capabilities. Other individual tree and stand variables were not related to increment core specific gravity.

Estimated Physical Properties

Using specific gravity values obtained from increment cores to estimate physical properties of wood avoids destructive sampling of trees. Expected variabilities in these properties also can be inferred from specific gravity variation.

Selected physical properties of Emory oak, therefore, were estimated from specific gravity of increment cores (table 1). Estimated physical properties of Emory oak were lower than those for Gambel oak determined earlier (Barger and Ffolliott 1972). These differences are reflected largely by the lower specific gravity values of Emory oak. This finding indicates that Emory oak has lower wood strength, stiffness, shock resistance and hardness than Gambel oak, and will produce a lower fiber and charcoal recovery than Gambel oak.

CONCLUSIONS

Conclusions drawn from this study are:

1. Specific gravity of Emory oak as estimated from increment cores was 0.567 ± 0.011.
2. Average tree specific gravity was correlated with increment core specific gravity, providing a basis

Table 1 - Estimated physical properties of Emory and Gambel oak[1].

Property	Unit of measure	Emory Oak	Gambel Oak[2]
Static bending:			
Fiber stress at proportional limit	Lb./in.^{2}	5.018	5,830
Modulus of rapture	Lb./in.^{2}	8,659	10,060
Modulus of elasticity	M Lb./in.^{2}	1,338	1,510
Work to maximum load	in.- Lb./in.^{3}	13	16
Total work	in.- Lb./in.^{3}	33	42
Impact bending:			
Fiber stress at proportional limit	Lb./in.^{2}	11,661	13,540
Modulus of elasticity	M Lb./in.^{2}	1,667	1,880
Height drop (50-lb hammer) causing failure	in.	42	52
Compression parallel to grain:			
Fiber stress at proportional limit	Lb./in.^{2}	2,977	3,350
Maximum crushing strength	Lb./in.^{2}	3,816	4,300
Compression perpendicular to grain:			
Fiber stress at proportional limit	Lb./in.2	837	1,090
Hardness:			
End	Lb.	1,043	1,365
Side	Lb.	954	1,249

[1] Based on equations developed by Markwardt (1935) and the USDA Forest Service (1956).

[2] From Barger and Ffolliott (1972).

to predict specific gravity of Emory oak trees without destructive sampling.

3. Of the individual tree and stand variables tested, only dbh and drc were related significantly to increment core specific gravity. However, these relationships have limited value in prediction.
4. Estimated physical properties of Emory oak were lower than those for Gambel oak, essentially because of the lower specific gravity of Emory oak.

LITERATURE CITED

Barger, R.L. and P.F. Ffolliott. 1964. Specific gravity of Arizona Gambel oak. USDA Forest Service Research Note RM-19, 2 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Barger, R. L. and P.F. Ffolliott. 1972. Physical characteristics and utilization of major woodland tree species in Arizona. USDA Forest Service Research Paper RM-83, 80 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Markwardt, L.J., and T.R.C. Wilson. 1935. Strength and related properties of woods grown in the United States. USDA Forest Service Forest Products Laboratory Technical Bulletin 479, 99 p. Forest Products Laboratory, Madison, Wisconsin.

Richardson, M.L., S.D. Clemmons and J.C. Walker. 1979. Soil survey of Santa Cruz and parts of Cochise and Pima counties, Arizona, 122 p. USDA Soil Conservation Service and Forest Service. Tucson, Arizona.

SAS Institute Inc. 1989. SAS/STAT User's guide: statistics, version 6. SAS Institute Inc., 1,686 p. Cary, North Carolina.

USDA Forest Service. 1956. Methods of determining the specific gravity of wood. USDA Forest Service Forest Products Laboratory Technical Note b-14, 6 p. Forest Products Laboratory, Madison, Wisconsin.

Fire Effects on Emory and Mexican Blue Oaks in Southeastern Arizona[1]

Anthony C. Caprio and Malcolm J. Zwolinski[2]

ABSTRACT

Quercus emoryi and *Q. oblongifolia* were sampled in a recently burned Madrean evergreen oak woodland to determine whether they were affected by fire and if response to burning differed by species. Sampling was carried out in Molino Basin, on the south slope of the Santa Catalina Mountains, southeastern Arizona, in the summer of 1985 following a June 1983 wildfire. A total of 544 trees were examined for fire effects by size class at 3 sites where both species occurred sympatrically. Fire effects, defined as trees surviving with crown alive, trees topkilled, or trees dead, were recorded for each individual. Additionally, the number of sprouts per tree was recorded at paired burned and unburned plots at each site. Trees in the burned plots corresponded to a subset of those examined for fire effects. Differences in effects were found between species and by size class but not by site. Overall mortality was low (11-15%) for both species, however fewer individuals of *Q. oblongifolia* died or were topkilled at larger size classes (>30 cm diameter) compared to *Q. emoryi*. In burned plots at least 94% of the living trees of both species produced sprouts while this varied from 8 to 16% in unburned plots. *Q. emoryi* was a more vigorous sprouter, initiating an average of 15 to 53 sprouts per tree while *Q. oblongifolia* produced 3 to 11. Greater resistance of *Q. oblongifolia* to fire may be important to its survival in a dry grassland savanna habitat where fast moving fires of comparatively high intensity but short duration are relatively frequent. Better sprouting ability of *Q. emoryi* may be a survival advantage in a habitat which often has a closed canopy of trees and shrubs, where fires are of decreased frequency but of higher intensity and longer duration and may often cause death of above-ground stems.

INTRODUCTION

Fire and the fire regime of an ecosystem, interacting with climate, topography, and other biotic factors, often play an important role in the distribution and composition of the plant communities the ecosystem encompasses. They are, however, often neglected as biotic factors because burns can be infrequent or because direct evidence of fire caused mortality or damage may not be apparent for an extended period after a burn although the effects may be long lasting. In the American Southwest fires have been relatively well studied in higher elevation pine and mixed conifer forests and lower elevation semi-desert grasslands (Wright and Bailey 1982). However, between these two biotic communities and grading into them is the Madrean evergreen woodland (Brown 1982) which has been poorly studied. Little is known about the effects or response of vegetation in this woodland to fire (Johnson et al. 1962; Wright and Bailey 1982; Niering and Lowe 1984) although the presence and importance fire as a biotic factor has long been noted (Leopold Wallmo 1955; Marshall 1957, 1963; Reeves 1976; Wagner 1977, Niering and Lowe 1984; Bahre 1991).

Madrean oak woodland has a distributional center in the Sierra Madre of Mexico with a northward extension into southern Arizona, New Mexico and Texas (Whittaker and Niering 1965; Brown 1982). Related oak woodlands are found in California and were derived from a common ancestral vegetation assemblage (Axelrod 1975, 1979). Fire is an important disturbance factor in many ecosystems (Pickett and White 1985; Sousa 1984) and plays a role in the development and structuring of many oak woodland communities, and in the evolution of species within them (Naveh 1975; Gill 1977, 1981; Trabaud 1984; Malanson and Trabaud 1988).

The purpose of our study was to evaluate the effects of fire on *Quercus emoryi* (Emory oak) and *Q. oblongifolia* (Mexican blue oak), two common oak species in southeastern Arizona. *Q. oblongifolia* has a more restricted distribution than *Q. emoryi*, being found at lower elevations and more xeric sites. *Q. emoryi* is common and widespread, occurring at elevations between 1200 and 1850 m (Whittaker and Niering 1965). We sampled three sites with different aspects with the objective of ascertaining what the fire effects were on the two species, how these effects might vary with site, whether the effects differed for a species at different sites, and if tree size and sprouting ability are important factors in understanding these effects.

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[1] Paper presented at the symposium on the Ecology and Management of Oak and Associated Woodlands: Perspectives in the Southwestern United States and Northern Mexico. Sierra Vista, AZ, April 27-30, 1992.

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STUDY AREA

Our study area was in Molino Basin, in the Santa Catalina Mountains, 40 km northeast of Tucson, Arizona (**Figure** 1). Sites were located on a south-facing slope in the upper western portion of the basin, on an east-to southeast-facing slope in the eastern end of the basin, and on a north-facing slope on the ridge forming the southern margin of the basin. Elevation ranges from 1460 to 1590 m.

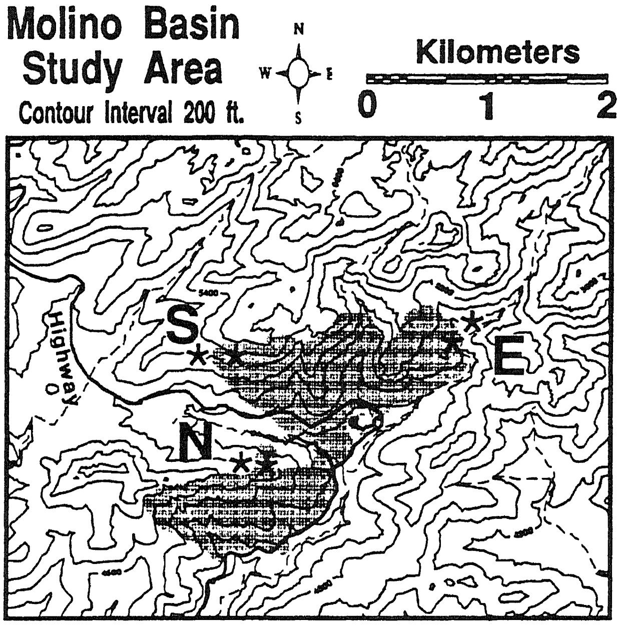

Figure 1. Locations of areas sampled in the Santa Catalina Mountains; south (S), east (E), and north (N) aspects. Asterisks within the shaded area (burn perimeter) are the inventoried sites.

Climate of the area is sub-humid characterized by low rainfall, high temperatures and evaporation and low humidity. A wet summer monsoon is proceeded by a consistent foresummer drought and usually followed by a fall dry period. A second peak in moisture occurs in the winter. Lightning caused fires are possible in southern Arizona from April through November with peak occurrence at the end of July (Bock et al. 1976; Barrows 1978). Nearly 60 percent of the acreage burned by lightning fires in the National Forests of Arizona and New Mexico occurs during June (Barrows 1978). The fire we studied burned approximately 259 ha from June 28-30, 1983, a period of extreme fire danger. Fine fuel biomass clipped from 36 1 m^2 quadrats averaged 823, 658, and 414 $g \cdot m^{-2}$ on the south, east, and north slopes respectively.

Vegetation in the basin forms a gradient from semi-desert grassland (oak savanna) on south-facing slopes to moderately dense oak woodland on north-facing slopes. The three sites we selected for sampling represent: 1) very open oak woodland on the south-facing slope, 2) "open woodland" (Whittaker and Niering 1965) or "lower encinal" (Shreve 1915) on the southeast aspect, and 3) relatively dense oak woodland on the north-facing slope. Predominant cover components were graminoids on the south and east slopes and shrubs on the north slope.

METHODS

Field Sampling - We collected data during the summer of 1985, two years after the fire. A one-or two-year delay in sampling for fire effects in oaks is recommended by Plumb (1980) who investigated the response of oak species in California. Mortality or crown death of trees is often delayed although trunks may have been completely girdled by burning. Data on *Quercus emoryi* and *Q. oblongifolia* were collected from three sites within the burn. The size of the area we inventoried at each site varied with oak density. On the north slope it was further limited by the relatively small amount of area burned. Approximately 2 ha was inventoried on the south aspect, 1.5 ha on the east and 0.5 ha on the north aspect. We censused all trees at a site by identifying species and fire effect and measuring basal diameter. Fire effect was categorized as; 1) some portion of crown alive, 2) tree with above ground parts dead but sprouting from base (topkilled), 3) tree dead and no sprouting occurring. Data on oak sprouting was obtained from 3 randomly located plots within each inventory area and 3 in an adjacent unburned area. We tallied number of sprouts for each tree within these plots.

Statistical Analysis - Our analysis of the fire effects data was performed with contingency tables computed with PC/SAS FREQ procedures (SAS 1988). The likelihood ratio chi-square was used to test for independence among various criteria. Fisher's Exact Test was used for 2x2 tables. A significance level of 0.05 was used to reject the null hypotheses that criteria were not different across a table. Crosstabulations were made to assess: 1) whether differences among criteria such as sites, species and size classes existed regardless of fire effects and 2) whether or not fire effects were dependent on the various criteria, species, sites or size class frequencies. Oak sprout data were tested for differences between species, site and burned and unburned areas using ANOVA.

Size classes were established by dividing diameter data into classes of 5 cm intervals up to 35 cm (classes 1 to 7) with all individuals greater than 35 cm grouped into class 8. Fire effects data were further recoded into two additional variables: 1) trees that survived with either the crown alive or via sprouting, versus those that died (survival versus mortality); and 2) trees in which the crown survived versus those which were topkilled or died (resisted versus stem death).

RESULTS

A total of 544 trees were sampled (207 *Q. emoryi* and 337 *Q. oblongifolia*) at the three sites with 233 of these on the south slope, 211 on the east, and 100 on the north. Sample size for *Q. oblongifolia* on the north slope is small (15 with 6 in one class) and may not be representative of the area.

Using combined site data *Q. emoryi* had a greater number of small individuals whereas *Q. oblongifolia* had proportionally more large individuals (G=39.993, df=7, P<0.0001) (**Figure 2**). Size class distributions did not vary significantly among sites for *Q. emoryi* (G=14.518, df=14, P=0.412) but did for *Q. oblongifolia* (G=28.725, df=14, P=0.011) with a larger number of small individuals on the south slope (**Figure 3**). However, differences in size class between species within sites were found with a higher proportion of small *Q. emoryi* on the south slope (G=19.686, df=7, P=0.006) and on the east slope (G=22.561, df=7, P=0.002) but not on the north slope (G=11.445, df=7, P=0.120).

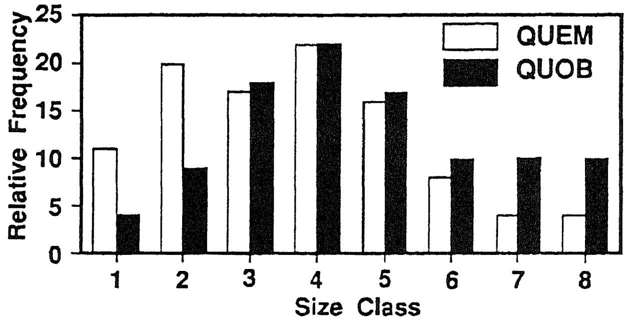

Figure 2. Overall size class distribution of *Q. emoryi* (QUEM) and *Q. oblongifolia* (QUOB).

Overall mortality was nearly equivalent between the two species across the different size classes (**Figure 4**). Fire effects were different between the species at each site (south G=13.638, df=2, P=0.001; east G=22.546, df=2, P<0.001; north G=7.023, df=2, P=0.03) but these effects were consistent among the sites for each species (*Q. emoryi* G=3.174, df=4, P=.529; *Q. oblongifolia* G=3.775, df=4, P<0.437). Fire effects also differed significantly among size classes for both species (*Q. emoryi* G=27.469, df=14, P=0.017; *Q. oblongifolia* G=85.086, df=14, P<0.001). Mortality was 11.1% for *Q. emoryi* and 14.2% for *Q. oblongifolia*. Percent mortality did not differ between the two species (Fisher's Exact Test; P=0.359) for the survival versus mortality criteria. However, a higher proportion of the crowns of *Q. oblongifolia* survived with some portion of their crown alive (61.4%) compared to *Q. emoryi* (38.2%) (Fisher's Exact Test; P<0.001).

Number of sprouts per tree was greater in burned areas than unburned areas (ANOVA; F=7.587, df=1, P=0.011) but did not differ among sites (F=1.369, df=2, P=0.274) (**Table 1**). However, the number of sprouts compared between species was not statistically different (F=3.136, df=1, P=0.089) although *Q. emoryi* had a slightly stronger response. No interaction effects were significant in the ANOVA.

Table 1. Mean number of sprouts per tree for each site (south, east, and north aspect) and species (*Q. emoryi* and *Q. oblongifolia*)

Species and Site		Unburned Mean	Unburned SD	Burned Mean	Burned SD
QUEM	(S)	0	-	15.33	(26.51)
	(E)	0	-	53.00	(58.64)
	(N)	0	-	16.78	(5.67)
QUOB	(S)	0.11	(0.19)	5.02	(4.50)
	(E)	0.08	(0.14)	10.77	(2.73)
	(N)	0	-	2.67	(4.62)

DISCUSSION

A greater proportion of *Q. oblongifolia* trees were in the largest size classes (> 30 cm dia.) than *Q. emoryi*, which had more trees than expected in the smaller size classes (< 10 cm dia.) when all samples are combined. This distribution might be explained by *Q. oblongifolia's* greater resistance to topkill by fire which allows more individuals to attain a large size. We noted that many large *Q. oblongifolia* on the south slope were located in small clusters of rocks which may offer some protection from fire. This distribution was maintained for *Q. emoryi* and for *Q. oblongifolia* at the south and east sites with large samples.

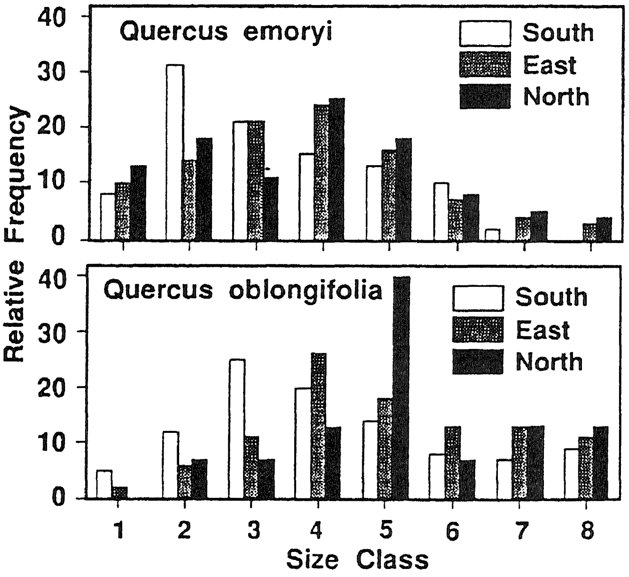

Figure 3. Size class distribution of *Q. emoryi* and *Q. oblongifolia* at each inventoried site.

Little fire-induced mortality was shown for either species by our data, although species were affected differently by burning. *Q. oblongifolia* was more resistant to fire with this resistance increasing with size whereas *Q. emoryi* in the same size classes was comparatively less resistant. *Q. emoryi* may rely more heavily on a sprouting response to maintain populations following burns. In other studies of evergreen oaks in southeastern Arizona, Meyer (1988) found *Q. emoryi* produced more coppice sprouts after cutting than *Q. arizonica*, a species closely related to *Q. oblongifolia*, with similar results following fire (Babb 1992). Variable resistance and sprouting response to fire are also found in woodland oaks in California (Plumb 1980).

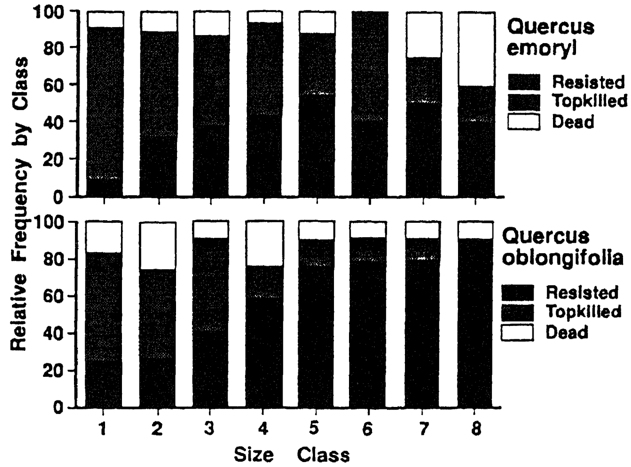

Figure 4. Fire effects on *Q. emoryi* and *Q. oblongifolia* for combined site data.

Bark thickness is an important factor in determining differential survival of some oak species in California (Plumb 1980). Thicker bark develops more rapidly for smaller diameter *Q. oblongifolia* than for *Q. emoryi* but at larger diameters thickness appears similar (unpublished data). Other structural or compositional properties of the bark were also observed while measuring bark thickness and could affect fire resistance. *Q. oblongifolia* bark is dry, rough and comparatively flaky while *Q. emoryi* bark is moist and only moderately ridged, particularly in smaller size classes, and thus may be a better conductor of heat into living tissue.

Greater resistance of *Q. oblongifolia* to fire may be important in its survival in dry savannas where fast-burning low-intensity fires may occur frequently in the fine graminoid fuels. Because of its limited resistance and its reliance on sprouting to survive fire, *Q. emoryi* may be prevented from establishing in these same habitats. It may be more restricted to sites with less frequent but more severe fires. An examination of fire effects on *Q. oblongifolia* from more mesic sites, with a larger sample than ours, might show reduced survival as fire severity overcomes this species' ability to resist. Differences in resistance and response to fire suggests that fire may play a role in determining distributions of these species because each has a differential advantage in habitats where fires of dissimilar frequency or severity occur. This pattern has been implied for other communities as well (Anderson 1982; Wright and Bailey 1982; Barton 1991). Thus selective mortality (topkill) and response of plants, coupled with a particular fire regime, can be important in arranging species distributions and community composition and dynamics, although any understanding of community structure must be combined with a knowledge of other attributes such as climate, topography, productivity, and competitive ability.

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REFERENCES

ANDERSON, R.C. 1982. An evolutionary model summarizing the roles of fire, climate, and grazing animals in the origin and maintenance of grasslands. In: J.R. ESTES, R.J.TYRL, and J.N. BRUNKEN (eds), Grasses and Grasslands. Univ. of Okla. Press.

AXELROD, D.I. 1975. Evolution and biogeography of Madro-Tethyan sclerophyll vegetation. Annals of the Missouri Botanic Gardens 62:280-334.

------. 1979. Age and origin of Sonoran Desert vegetation. Occasional Papers of the Calif. Acad. of Sci., No. 132, 74 pp.

BABB, G.D. 1992. Sprouting response of *Quercus arizonica* and *Quercus emoryi* following fire. MS Thesis, Univ. of Ariz. 78 pp.

BAHRE, 1991. A Legacy of Change: Historic Human Impact on Vegetation of the Arizona Borderlands. Univ. of Ariz. Press, Tucson. 231 pp.

BARROWS, J.S. 1978. Lightning fires in Southwestern forests. Final Report by Colorado St. Univ. for Intermtn. For. and Range Exp. Stn., under cooperative agreement 16-568-CA USDA FS, Ft. Collins, CO. 154 pp.

BARTON, A.M. 1991. Factors controlling the elevational positions of pines in the Chiricahua Mountains, Arizona: drought, competition, and fire. PhD. Dissertation, Univ. of Mich., 162 pp.

BOCK, J.E., C.E. BOCK and J.R. McKNIGHT. 1976. A study of the effects of grassland fires at the research ranch in southeast Arizona. Ariz. Acad. Sci. 11:49-57.

BROWN, D.E. (ed). 1982. Biotic communities of the American southwest United States and Mexico. Desert Plants 4(1-4). Boyce Thompson Arboretum, Superior, AZ, Univ. of Ariz. Press. 342 pp.

GILL, A.M. 1977. Plant traits adaptive to fires in Mediterranean land ecosystems. In: MOONEY, H.A.

and C.E. CONRAD (eds), Proc. of the Symp. on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems. USDA FS GTR WO-3, 498 pp.

------. 1981. Fire adaptive traits of vascular plants. In: MOONEY, H.A., T.M. BONNICKSEN, N.L. CHRISTENSEN, J.E. LOTAN, W.A. REINERS (eds), Proc. of the Conf.; Fire Regimes and Ecosystem Properties. USDA FS GTR WO-26 pp. 208-230.

JOHNSON, D.E., H.A.M. MUKHTAR, R. MAPSTON and R.R. HUMPHREY. 1962. The mortality of oak-juniper woodland species following a wildfire. J. Range Mgmt. 15:201-205.

LEOPOLD, A.S. 1924. Grass, brush, timber and fire in southern Arizona. J. For. 22:1-10.

MALANSON, G.P. and L. TRABAUD. 1988. Vigour of post-fire resprouting by *Quercus coccifera* L. J. Ecol. 76:351-365.

MARSHALL, J.T. Jr. 1957. Birds of the pine-oak woodland in southern Arizona and adjacent Mexico. Cooper Ornith. Society. Pacific Coast Avifauna 32:125.

------. 1963. Fire and birds in the mountains of southern Arizona. In: Proc. Tall Timbers Fire Ecol. Conf. 2:135-141.

MEYER, J.W. 1988. First year coppice regeneration of *Quercus emoryi* and *Quercus arizonica* in the Huachuca Mountains, Arizona. M.S. Thesis, Univ. of Ariz., Tucson, AZ, 55 pp.

NAVEH, Z. 1975. Evolutionary significance of fire in the mediterranean region. Vegetatio 29:199-208.

NIERING, W.A. and C.H. LOWE. 1984. Vegetation of the Catalina Mountains: community types and dynamics. Vegetatio 58:3-28.

PICKETT, S.T.A. and P.S. WHITE. 1985. Patch dynamics: A synthesis. In: S.T.A. Pickett and P.S. White (ed.), The Ecology of Natural Disturbance and Patch Dynamics. New York, Acad. Press. pp 371-384.

PLUMB, T.R. 1980. Response of oaks to fire. In: Proc. of the Symp. on the Ecology, Management, and Utilization of California oaks. June 26-28, 1979. Claremont, CA. USDA FS GTR PSW-44.

REEVES, T. 1976. Vegetation and flora of Chiricahua National Monument, Cochise County, Arizona. MS Thesis, Ariz. St. Univ. 180 pp.

SAS. 1988. SAS/STAT User's Guide, Release 6.03 Edition. SAS Institute Inc. 1028 pp.

SHREVE, F. 1915. The vegetation of a desert mountain range as conditioned by climatic factors. Carnegie Inst. of Wash., Wash. DC. 112 pp.

SOUSA, W.P. 1984. The role of natural disturbance in natural communities. Annual Rev. of Ecol. and Systematics, 15:353-391.

TRABAUD, L. 1984. Fire adaption strategies of plants in the French Mediterranean area. In: N.S. MARGARIS, M. ARIANOUTSOU-FARRAGITAKI, and W.R. OECHEL (eds), Being Alive on Land. pp. 63-69. W.Junk, The Hague.

WAGNER, W.L. 1977. Floristic affinities of the Animas Mountains, southwestern New Mexico. MS Thesis, Univ. of New Mexico, Albuquerque, 82 pp.

WALLMO, O.C. 1955. Vegetation of the Huachuca Mountains, Arizona. Amer. Midl. Nat. 54:466-480.

WHITTAKER, R.H. and W.A. NIERING. 1965. Vegetation of the Santa Catalina Mountains, Arizona: II. A gradient analysis of the south slope. Ecol. 46:429-452.

WRIGHT, H.A. and A.W. BAILEY. 1982. Fire Ecology, United States and Southern Canada. John Wiley and Sons. New York

Estimating Volume and Biomass for Dryland Oak Species[1]

David C. Chojnacky[2]

Volume equations were developed for Arizona and New Mexico's *Quercus arizonica*, *Q. emoryi*, *Q. hypoleucoides*, *Q. oblongifolia*, *Q. gambelii* and unidentified evergreen *Quercus* species. The equations were constructed from visually-measured volumes and diameter and height measurements. The volume estimates included wood and bark of all branches 3.8 cm (1.5 in) and larger. Specific gravity, available for several species, was used to convert volume predictions to weight. Weight of branches, foliage, and roots was estimated by modifying equations published for the Mediterranean *Quercus ilex*.

INTRODUCTION

Oaks occur in almost every State in the United States. Most species are deciduous, shedding their leaves in the fall. But in the Southwestern States many oak species are called evergreen because they shed their leaves in the spring just after new-leaf growth (fig. 1). At least 12 oak species have been identified in Arizona and New Mexico (Little 1976).

New information on oak in Arizona and New Mexico is available from recent inventories coordinated or conducted by the Forest Service, U.S. Department of Agriculture, through its Intermountain Forest Inventory and Analysis group (commonly called FIA and referred to administratively as the Interior West Resource Inventory, Monitoring, and Evaluation Program). About 17 percent and 13 percent of forest trees in the two respective States are oak (Conner et al. 1990; Van Hooser et al. in press). Those reports list about a half-million ha (1.3 million acres) of oak forest type in Arizona and New Mexico. A closer look at the data shows much oak occurring within pinyon-juniper and ponderosa pine forest types. The total area where oak occurs is about 3.7 million ha (9.2 million acres), or roughly seven times the area of pure oak forest type.

The inventories reported the following evergreen oaks: *Quercus arizonica* Sarg., *Q. emoryi* Torr., *Q. hypoleucoides* A. Camus, *Q. oblongifolia* Torr., and an unidentified *Quercus* group. Foliage and bark differences were the primary means used to separate species, but these differences were often obscured by some species' tendencies to hybridize. The unidentified *Quercus* group likely included *Q. grisea* Liebm., *Q. turbinella* Greene, *Q. undulata* Torr., *Q. chrysolepis* Liebm., and some of the reported species plus associated hybrids. A single deciduous oak, *Q. gambelii* Nutt., was also inventoried.

Figure 1. Evergreen oak (likely *Quercus hypoleucoides*) in the Santa Catalina Mountains near Tucson, AZ.

Volume equations have been developed for oak in Arizona (Chojnacky 1988a, 1988b), but none have been constructed for New Mexico's oak. Oak biomass equations for southwestern species have only been developed for small-diameter *Q. hypoleucoides* saplings (Whittaker and Niering 1975).

The objectives of this study were to (1) consider data source, stem structure, and species differences in determining the number of oak volume equations needed for Arizona and New Mexico and (2) convert the volume predictions to weight by modifying equations developed for the Mediterranean *Q. ilex* L.

DATA

Sampling and Measurements

Data were collected in Arizona and New Mexico using Intermountain FIA procedures. Oak trees were measured on 292 plots (fig. 2). The sample included sites dominated by oak, pinyon, or juniper species, but it omitted oaks on sites dominated by ponderosa pine, Douglas-fir, white fir, or other timberland species. The plots were subsampled from inventory plots permanently established in a 5,000-m or double 10,000-m grid across the two States (a few ownerships used slightly smaller or larger grids). More

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[1] *Paper presented at Ecology and Management of Oaks and Associated Woodlands: Perspectives in the Southwestern United States and Northern Mexico, Sierra Vista, AZ, April 27-30, 1992.*

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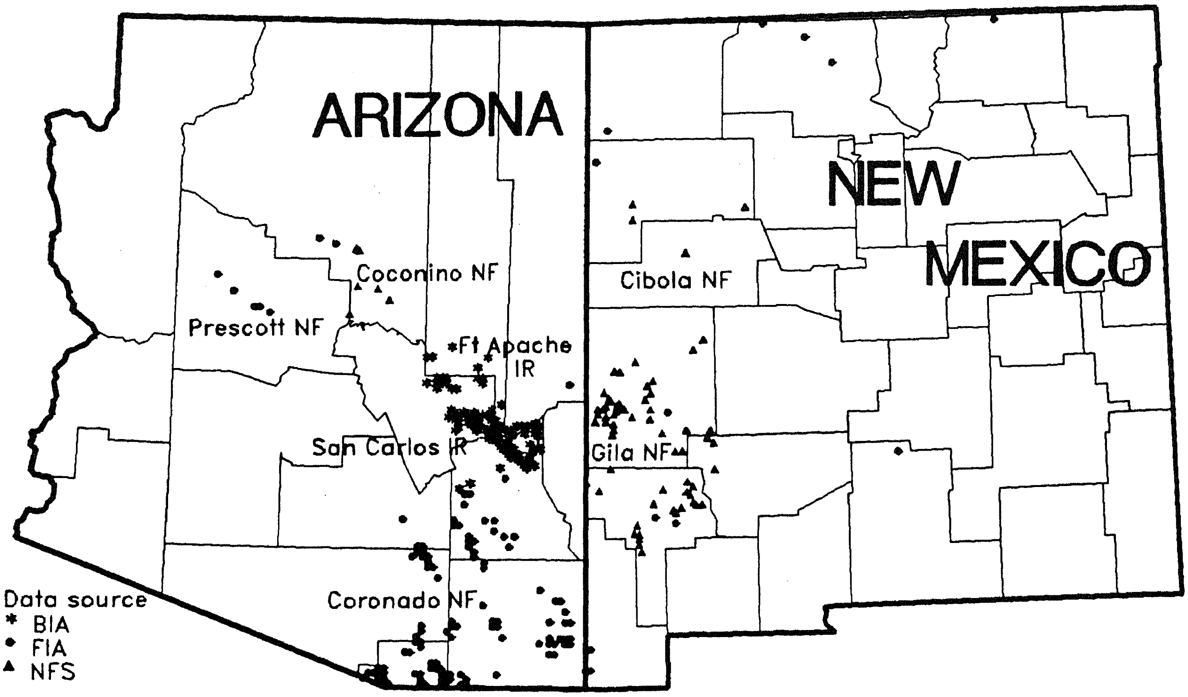

Figure 2. Forest Inventory and Analysis (FIA), Bureau of Indian Affairs (BIA), and National Forest System (NFS) crews measured oak volumes at 292 plots, mostly in National Forests (NF) and Indian Reservations (IR).

than half of the field work was done by FIA crews, but Bureau of Indian Affairs (BIA), U.S. Department of the Interior, and National Forest System (NFS) crews contributed some data (table 1).

FIA guidelines defined a tree as a plant having one or more stems originating from a single root system. At least one stem had to have a 7.6-cm (3.0-in) basal diameter.

A total of 681 oak trees were measured. Major species in the data were *Q. arizonica* (235), unidentified *Quercus* (228), and *Q. emoryi* (130). *Quercus arizonica* and *Q. emoryi* were among the easier species to identify, but even these may have been called unidentified *Quercus* by some crews.

Wood volume for each oak tree was determined by dividing a tree's stems and branches into segments

Table 1 – Oak volume data sampled in Arizona and New Mexico, 1981 to 1988.

Species[1]	State	No. of trees	Mean volume	Mean DRC	DRC percentiles 5th	50th	max	Mean height	Single-stem trees	Data sources BIA	FIA	NFS
			dm^3	cm	cm	cm	cm	m	%	%	%	%
Quar	Arizona	156	180	29	12	26	75	4.3	56	76	24	0
	New Mexico	79	83	22	12	20	67	3.1	48	0	0	100
	Total	235	148	26	12	23	75	3.9	54	51	16	34
Quem	Arizona	123	112	24	11	22	66	4.3	58	33	67	0
	New Mexico	7	80	23	15	21	43	3.9	71	0	14	86
	Total	130	110	24	11	21	66	4.3	58	32	64	5
Quercus[2]	Arizona	222	125	24	9	21	68	3.8	57	19	81	0
	New Mexico	6	53	22	9	23	32	3.4	33	0	100	0
	Total	228	123	24	9	22	68	3.8	57	18	82	0
Quga	Arizona	24	352	27	12	20	71	7.3	83	50	21	29
	New Mexico	24	55	15	9	12	29	4.8	88	0	50	50
	Total	48	204	21	9	17	71	6.0	85	25	35	40
Quhy	Arizona only	23	54	19	8	16	45	4.0	57	0	100	0
Quob	Arizona only	17	123	24	8	18	53	4.1	71	0	100	0
	Grand total	681	132	24	10	22	75	4.1	58	31	53	15

[1] *Quercus arizonica* (Quar); *Q. emoryi* (Quem); *Q. gambelii* (Quga); *Q. hypoleucoides* (Quhy); *Q. oblongifolia* (Quob).
[2] Could include any evergreen oak occurring in Arizona or New Mexico.

for systematic counting (Born and Chojnacky 1985). Segments were grouped into 5.0-cm (2.0-in) midpoint diameter classes having length sections less than 1.8 m (6.0 ft). Length sections were identified to the nearest 0.3-m (1.0-ft) midpoint class. The smallest diameter class was a little less than 5.0 cm, ranging from 3.8 to 7.6 cm (1.5 to 3.0 in). Some segment dimensions in lower portions of trees were measured, but most were estimated by sight.

Volume was computed for each segment with Huber's formula (Husch et al. 1982, p. 101) by using midranges of the diameter and length classes for segment dimensions. Huber's formula has been shown to give biased results when class midranges are substituted for exact dimensions (Chojnacky and Born 1992). Replacing the class midranges with a better estimator would require another study to destructively sample oak segment dimensions. To compensate for this lack of information, an inadvertent practice from past work was continued, using 5.1 cm (2.0 in) for the smallest diameter class in place of its actual midrange (5.7 cm or 2.25 in). This practice compensates for some of the bias incurred by using midranges in Huber's formula (Chojnacky and Born 1992).

Summation of tree segments produced a volume estimate that included wood and bark of all aboveground stem and branch material larger than 3.8 cm (1.5 in) in diameter. Both live and dead wood were lumped in volume calculations.

Tree variables measured to develop volume equations were total height (HT), diameter at groundline near the root collar (DRC), and number of basal stems. Diameter at breast height (DBH) was also collected for the single-stem trees measured by BIA crews.

For trees forking at the root collar, diameter equivalent (EDRC) was calculated for use in place of DRC (Batcheler 1985):

$$EDRC = \sqrt{\sum_{i=1}^{n} d_i^2} \qquad (1)$$

where

n = number of basal stems 3.8 cm (1.5 in) or larger
d_i = basal diameter of the ith stem.

Data Checking and Grouping

Several data items were examined: (1) BIA, FIA, and NFS data sources, (2) multiple- and single-stem trees, and (3) species groupings. Data were examined by overlaying quadratic regression lines and confidence intervals on graphs of volume-to-DSQH (diameter squared height) for various groupings. The confidence intervals were computed for predicted means at the 95 percent level (Neter and Wasserman 1974, p. 233). Diameter squared height was computed as DRC^{2}HT/2,000 or EDRC^{2}HT/2,000 (divided by 1,000 rather than 2,000 for English units). Comparisons were done for two groups, DSQH less than 2,000 and DSQH more than 2,000, to separate the highly variable large trees from smaller trees.

In retrospect, the visual segmentation procedures could give biased results by allowing field crews too much flexibility in classifying segments (Chojnacky and Born 1992). This complicated assessing apparent differences between BIA, FIA, and NFS data. Because the sources gathered data from different geographic areas, these differences could have been due either to technique bias or tree growth forms. One finding was that more difference existed between data sources than between Arizona and New Mexico data from the same source.

Multiple-stem trees (those with two or more basal stems) were compared to single-stem trees. For given tree dimensions, multiple-stem trees generally had lower volumes than single-stem trees. However, the two stem forms yielded similar volumes when data were drawn only from plots with both multiple- and single-stem trees. This raises concern about separation of the data into multiple- and single-stem groups when constructing volume equations. Perhaps the two stem forms could be better differentiated by site characteristics than by stem structure.

Species comparisons were complicated because a third of the trees were only identified by genus (*Quercus* in table 1). The unidentified *Quercus* also may have included some species that were correctly identified elsewhere. Quadratic regression results showed *Q. arizonica* and unidentified *Quercus* were similar, but both species were different from *Q. emoryi*. Too few *Q. hypoleucoides* and *Q. oblongifolia* were identified to make inferences about species differences. Even though *Q. gambelii* is a deciduous species, its volume relationship appeared similar to evergreen species. Perhaps this was because the sample did not include the species' full range. No samples were taken on timberland sites where *Q. gambelii* mixed with ponderosa pine and other conifers.

In summary, the data checks provided little evidence for either grouping or separating data. The three factors considered – data source, stem structure, and species – all appeared worthwhile for further study. In the absence of such study, a conservative approach was used. All data were grouped to construct three volume equations for *Quercus*:

1. An equation for all data combined.
2. A multiple-stem equation.
3. A single-stem equation.

Separate multiple- and single-stem equations were constructed more to be compatible with previous publications than for analytical reasons.

VOLUME MODELING

Graphical analysis showed no reason to change the oak volume model used earlier (Chojnacky 1988b):

$$V = \begin{cases} \beta_0 + \beta_1 X + \beta_2 X^2 & \text{for } X \le X_0 \\ \beta_3 + \beta_1 X + \beta_4 / X & \text{for } X > X_0 \end{cases} \qquad (2)$$

where

V = gross volume of wood and bark of all stems and branches
X = $DSQH$ (diameter squared height)
β's, X_0 = parameters estimated from the data.

Table 2 – Volume and biomass equations and parameters for Arizona and New Mexico oaks.

Measurement units	Species[1]	Equation component[5]	Basal stem form[3]	Branch diameter (bd)	Parameter estimates β_0	β_1	β_2	X_0	No. of trees	Fit statistics R^2	CV
				cm or in.							
metric	Qusp	volume (V_{bd})	M & S	>3.8	-1.5107	66.462	1.3694	6.9850	681	0.93	46
		volume (V_{bd})	S	>3.8	-2.0753	72.488	1.1003	6.9850	397	0.93	49
		volume (V_{bd})	M	>3.8	-2.0498	62.230	0.9747	6.9850	284	0.89	40
	Quga	weight (W_{bd})	M & S	>3.8	0.6340				48		5
	Quem	weight (W_{bd})	M & S	>3.8	0.5670				115		11
	Quil	branches (W_B)	S[4]	<5.0	0.2264	0.7752	-0.0162		397	1.00	0
		foliage (W_F)	S[4]		-0.6210	0.8382	-0.0307		397	1.00	0
		roots (W_R)	S	>1.0	-0.2120	0.8940			30	0.83	
	Quae[2]	DBH	S		-2.2542	0.7812	0.3081		189	0.94	11
	Quga	DBH	S		-1.4644	0.8841	0.0000		192	0.98	10
English	Qusp	volume (V_{bd})	M & S	>1.5	-0.0534	2.3077	0.0467	7.1046	681	0.93	46
		volume (V_{bd})	S	>1.5	-0.0733	2.5170	0.0376	7.1046	397	0.93	49
		volume (V_{bd})	M	>1.5	-0.0724	2.1608	0.0333	7.1046	284	0.89	40
	Quga	weight (W_{bd})	M & S	>1.5	0.6340				48		5
	Quem	weight (W_{bd})	M & S	>1.5	0.5670				115		11
	Quil	branches (W_B)	S[4]	<2.0	0.3036	0.7752	-0.0049		397	1.00	0
		foliage (W_F)	S[4]		-0.5655	0.8382	-0.0094		397	1.00	0
		roots (W_R)	S	>0.4	-0.1756	0.8940			30	0.83	
	Quae[2]	DBH	S		-0.8875	0.7812	0.0370		189	0.94	11
	Quga	DBH	S		-0.5766	0.8841	0.0000		192	0.98	10

[1] Qusp includes all *Quercus* in table 1; *Quercus gambelii* (Quga); *Q. emoryi* (Quem); *Q. ilex* (Quil).

[2] Quae includes *Q. arizonica* and *Q. emoryi.*

[3] M=2 or more basal stems per tree (multiple-stem); S=1 basal stem per tree (single-stem).

[4] Includes individual stems from multiple-stem trees.

[5]

$$^5V_{bd} = \begin{cases} \beta_0 + \beta_1 X + \beta_2 X^2 & \text{for } X \le X_0 \\ \beta_0 + \beta_1 X + \beta_2\left(3{X_0}^2 - 2{X_0}^3/X\right) & \text{for } X > X_0 \end{cases}$$

$$W_{bd} = \beta_0 \cdot V_{bd} \cdot D_{H_2O}; \quad \text{where } \beta_0 = \text{specific gravity}$$

$$W_B, W_F = 10^{[\beta_0 + \beta_1 Log_{10}(W_{bd}) + \beta_2 HT]}; \quad \text{where } bd > 5.0 \text{ cm or } 2.0 \text{ in}$$

$$W_R = 10^{[\beta_0 + \beta_1 Log_{10}(W_{bd} + W_B + W_F)]}; \quad \text{where } bd > 5.0 \text{ cm or } 2.0 \text{ in}$$

$$DBH = \beta_0 + \beta_1 DRC + \beta_2 HT$$

where

$V_{bd} =$ gross outside-bark bole volume including branches $> bd$ (dm^3 or ft^3)

$X = DRC^2HT/2{,}000$ for *metric units* or $DRC^2HT/1{,}000$ for *English units*

$DRC =$ tree diameter near root collar (cm or in)

$HT =$ perpendicular distance from groundline to top of tree's tallest stem (m or ft)

$W_{bd} =$ outside-bark oven-dry bole weight including branches $> bd$ (kg or lbs)

$D_{H_2O} =$ density of water (1 kg/dm^3 or 62.4 lbs/ft^3)

$W_B =$ outside-bark oven-dry branch weight $<$ 5.0-cm or 2.0-in bd (kg or lbs)

$W_F =$ oven-dry foliage weight (kg or lbs)

$W_R =$ outside-bark oven-dry root weight $>$ 1.0-cm or 0.4-in bd (kg or lbs)

$DBH =$ tree diameter at breast height (cm or in).

Equation 2 was further simplified by imposing two restrictions to make the two-part model smooth and continuous at X_0:

$$\beta_3 = \beta_0 + 3\beta_2 {X_0}^2 \qquad (3)$$

$$\beta_4 = -2\beta_2 {X_0}^3 \qquad (4)$$

Resulting substitution reduced the number of parameters from 6 to 4:

$$V = \beta_0 + \beta_1 X + \beta_2 X' \qquad (5)$$

where

$$X' = \begin{cases} X^2 & \text{for } X \le X_0 \\ 3{X_0}^2 - 2{X_0}^3/X & \text{for } X > X_0 \end{cases}$$

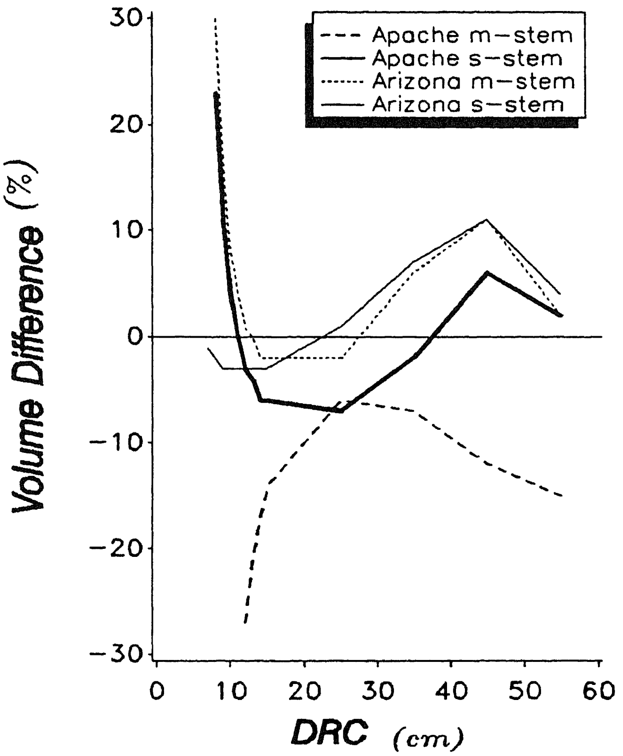

Figure 3. Comparison of multiple(m)- and single(s)-stem volume predictions to previous oak equations for Arizona (Chojnacky 1988b) and Fort Apache and San Carlos Apache Indian Reservations (Chojnacky 1988a).

Nonlinear regression (Gauss-Newton Taylor series computation method [SAS 1989, p. 1153]) was used to estimate beta$_0$, beta$_1$, beta$_2$, and X_0 for all data combined (table 2, V_{bd}). Parameter estimation for multiple- and single-stem equations was simplified by using X_0 from the combined data and then estimating the beta's by linear regression. Keeping X_0 the same for all three equations ensured similar form among the equations and avoided illogical crossovers between equations. All regressions used a weight of DSQH$^{-1.5}$ to stabilize volume variation among different tree sizes. Several other powers of DSQH were examined, but -1.5 seemed adequate. Two goodness-of-fit statistics – the coefficient of variation (CV) and the coefficient of determination (R^2) – were computed from regression residuals without considering regression weights.

The multiple- and single-stem equations agreed within ± 15 percent to previously developed Arizona equations, except for the smallest trees where actual differences tend to be exaggerated by percentages (fig. 3). The close agreement was not surprising because the previous equations were developed from subsets of this study's data. Data check findings (of data source differences and possible bias) indicate little reason to justify different equations for locals areas within the Southwest. It is probably best to use this study's oak equations for all of Arizona and New Mexico to keep possible equation bias constant.

Table 3 – Comparing specific gravities between oak and several other dryland forest species.

	Specific gravity			
Species[1]	Wood	Wood and Bark	n	Data source
Quem	0.57	115		Maingi and Ffolliott (this proceedings)
Quga	0.63		48	Barger and Ffolliott (1972)
Cele	0.81	0.70	36	Chojnacky (1984)
Jusp	0.56	0.54	10	Chojnacky (in preparation)
Pied	0.51	0.50	8	Chojnacky (in preparation)
Prve	0.70	0.69	12	Chojnacky (1991)

[1] *Quercus emoryi* (Quem); *Q. gambelii* (Quga); *Pinus edulis* (Pied); *Juniperus deppeana, J. monosperma,* and *J. osteosperma* (Jusp); *Cercocarpus ledifolius* (Cele); *Prosopis velutina* (Prve).

BIOMASS ESTIMATION

Biomass of the main tree stem can be estimated by using specific gravity (from other studies) to convert volume predictions to weight (W):

$$W = \beta_0 \cdot V \cdot D_{H_2O} \qquad (6)$$

where

β_0 = specific gravity
V = volume from eq. 5
D_{H_2O} = density of water.

Specific gravity has been estimated for just 2 of the 12 southwestern oak species, *Q. gambelii* and *Q. emoryi*. These values were for wood without bark (table 3). It would be more appropriate to use specific

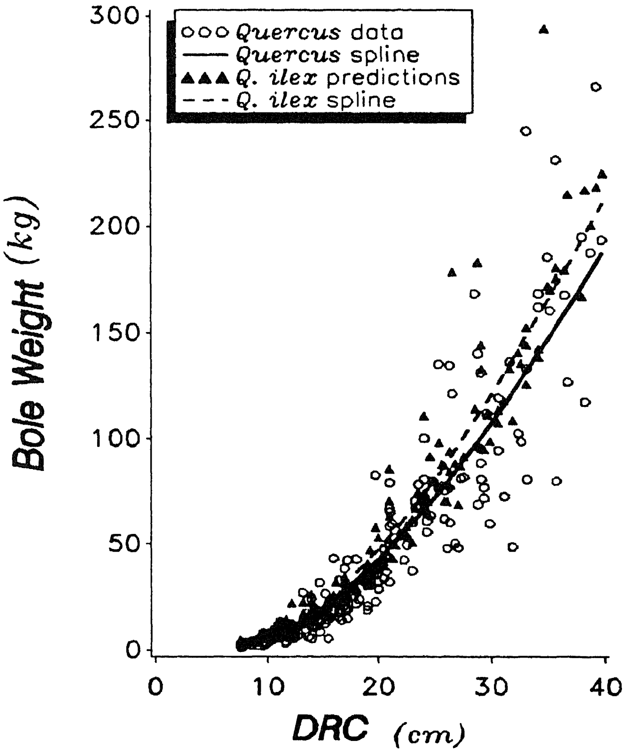

Figure 4. *Quercus ilex* bole weight predictions (> 5.0-cm branch diameter) compared to Arizona and New Mexico *Quercus* data (> 3.8-cm branch diameter). *Quercus* weights were computed using 0.567 specific gravity for *Q. emoryi* and 0.634 for all other species. The curves were interpolated with spline routines.

gravity of wood and bark combined in equation 6 because volume predictions from equation 5 include bark. Data from other dryland tree species show the combined specific gravity of wood and bark can be 0.01 to 0.11 less than that of wood alone (table 3). However, the difference between the specific gravity of oak wood and oak bark could be minimal. Sackett (1980) reported a *Q. gambelii* wood and bark specific gravity of 0.635 (for 1- to 3-in diameter branches) that is nearly identical to Barger and Ffolliott's (1972) wood value of 0.634.

A study from Spain reported tree bole, branch, foliage, and root weight component equations for the Mediterranean evergreen oak, *Q. ilex* (Canadell and Roda 1991; Canadell et al. 1988). This work was done on single-stem trees and individual stems of multiple-stem trees ranging from 5.3 to 24.4 cm (2.1 to 9.6 in) DBH. Because the equation required DBH measurements, a DRC-to-DBH conversion was developed from single-stem data available from BIA inventories (table 2).

Predictions for *Q. ilex* bole weights were within the range of the Arizona/New Mexico oak data (fig. 4), but they seemed high. This was contrary to expectations because *Q. ilex* included a little less wood per tree. *Quercus ilex* bole weight equations just included stems and branches larger than 5.0-cm branch diameter (bd), whereas this study included all stems and branches larger than 3.8-cm bd.

The specific gravity in the volume-to-weight conversion also could have affected the comparison of *Q. ilex* equations to Arizona/New Mexico data. A specific gravity of 0.567 was used for *Q. emoryi* and 0.634 (the *Q. gambelii* value) for all other species. *Quercus gambelii* and most of the other species were white oaks. Specific gravities for red oaks, such as *Q. emoryi*, are lower than for white oaks (Forest Products Laboratory 1987).

The *Q. ilex* equations could be used directly on Arizona and New Mexico *Quercus* data. However, an alternative was developed because of specific gravity uncertainties and other possible incompatibilities. The alternative allowed all biomass components to be predicted from a common volume (converted to weight). This ensured that the choice of a specific gravity for volume-to-weight conversion affected all biomass components equally.

To construct the alternative, foliage, branch, and tree bole weights were predicted for single-stem *Quercus* data. The foliage (W_F) and branch (W_B) weights were then modeled as functions of tree weight (W_5) and height (HT):

$$Log_{10}(Y) = \beta_0 + \beta_1 Log_{10}(W_{5.0}) + \beta_2 HT \qquad (7)$$

where $Y = W_B$ or W_F

$W_{5.0} = Q.\ ilex$ weight for $bd > 5.0$ cm

β's = parameters estimated from regression.

Following Canadell's original modeling, base-10 logarithmic regression was used to estimate parameters. Because the "data" were highly correlated predictions, the regression fit was nearly perfect (table 2, W_B and W_F), adding no additional error to Canadell's original work. These "refit" equations avoided the need for a DBH measurement and maintained proportionality among biomass components.

To estimate foliage and branch weights for Arizona and New Mexico *Quercus*, bole weight and height can be used in the refit *Q. ilex* equations (table 2). Data measurement definitions produce a 1.2-cm bd discrepancy from using *Quercus* weight in the refit *Q. ilex* equations. This discrepancy could be dealt with by using ratio equations developed for other dryland species. For example, there is about a 10 percent volume (or weight) difference between 3.8 cm-bd and 5.0 cm-bd for pinyon and juniper (Chojnacky 1987). It would also be reasonable to ignore the 1.2-cm difference. Since the actual minimum branch diameter for *Quercus* was visually determined, it most likely varied within several centimeters.

Once total aboveground biomass is determined – by summing the tree, branch, and foliage weight – roots larger than 1.0-cm (0.4-in) diameter can be estimated directly from Canadell and Roda's (1991) *Q. ilex* root equation (table 2, W_R). Canadell modeled root weight as a proportion of aboveground weight rather than as a function of tree dimensions. This equation was developed only from single-stem trees, because most multiple-stem trees had been harvested several times, leaving root systems much older and more developed than aboveground stems.

Canadell and Roda (1991) also estimated fine roots less than 1.0-cm diameter, but these were sampled on an area basis and could not be related to individual trees.

CONCLUSION

Oak volume equations were constructed for Arizona and New Mexico. Volume included wood and bark of all branches at least 3.8 cm (1.5 in) in diameter. Basal tree diameter and height must be measured to use the equations. Specific gravity from the literature (table 3) enabled conversion of volume to weight. Methodology to obtain branch, foliage, and root weights was developed from equations reported for a Mediterranean evergreen oak (*Q. ilex*).

All equations and parameters to estimate volume and biomass are in table 2. For example, the total biomass (W_{TB}) for a multiple-stem *Q. emoryi* with 45.0-cm DRC and 7.3-m HT would be calculated as follows:

Step 1. Volume (V_{bd}) > 3.8-cm bd:
$V_{3.8} = 510.691$ dm^3 (from *Quercus* multiple-stem equation)

Step 2. Volume > 3.8-cm bd converted to weight (W_{bd}):
$W_{3.8} = 289.562$ kg (from *Q. emoryi* equation)

Step 3. Branch weight (W_B) < 5.0-cm bd:
$W_B = 103.868$ kg (substituting $W_{3.8}$ for $W_{5.0}$ in *Q. ilex* equation)

Step 4. Foliage weight (W_F):
$W_F = 16.532$ kg (from *Q. ilex* equation)

Step 5. Root weight (W_R) > 1.0-cm bd:
$W_R = 132.982$ kg (from *Q. ilex* equation)

Step 6. Total biomass ($W_{TB} = W_{bd} + W_B + W_F + W_R$):
$W_{TB} = 542.944$ kg

Had the combined multiple- and single-stem volume equation been used, total biomass would have been about 9 percent larger.

Although volume data represented most of the oak range in Arizona and New Mexico, uncertainty in the data limited comparisons between species, tree forms, and other attributes. Therefore, to be conservative, data were lumped for equation construction. Future improvement should focus on more careful volume or biomass measurement, specific gravity determination for additional species, and better species identification. Ample inventory data exist to efficiently design future studies to sample the oak population in Arizona and New Mexico.

LITERATURE CITED

Barger, R.L. and P.F. Ffolliott. 1972. Physical characteristics and utilization of major woodland tree species in Arizona. Res. Pap. RM-83. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 80 pp.

Batcheler, C.L. 1985. Note on measurement of woody plant diameter distributions. New Zealand Journal of Ecology 8:129-132.

Born, J.D. and D.C. Chojnacky. 1985. Woodland tree volume estimation: a visual segmentation technique. Res. Pap. INT-344. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 16 pp.

Canadell, J., M. Riba, and P. Andres. 1988. Biomass equations for *Quercus ilex* L. in the Montseny Massif, northeastern Spain. Forestry 61(2):137-147.

Canadell, J. and F. Roda. 1991. Root biomass of *Quercus ilex* in a montane Mediterranean forest. Canadian Journal of Forest Research 21:1771-1778.

Chojnacky, D.C. 1984. Volume and biomass for curlleaf cercocarpus in Nevada.

Res. Pap. INT-332. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 8 pp.

Chojnacky, D.C. 1987. Estimating singleleaf pinyon and Utah juniper volumes for several utilization standards. Western Journal of Applied Forestry 2(2):51-55.

Chojnacky, D.C. 1988a. Woodland volume equations for Arizona Fort Apache and San Carlos Indian Reservations. Res. Note INT-379. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 7 pp.

Chojnacky, D.C. 1988b. Juniper, pinyon, oak, and mesquite volume equations for Arizona. Res. Pap. INT-391. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 11 pp.

Chojnacky, D.C. and J.D. Born. 1992. Dryland forest volume: another look at the visual segmentation technique. Res. Note INT-399. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 7 pp.

Chojnacky, D.C. 1991. Growth prediction for Arizona's mesquite (*Prosopis velutina*) woodlands. Forest Ecology and Management 42:293-310.

Chojnacky, D.C. [In preparation]. Volume and biomass estimation for New Mexico's pinyon-juniper dryland forests. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. Review draft.

Conner, R.C., A.W. Green, J.D. Born, and R.A. O'Brien. 1990. Forest resources of Arizona. Resour. Bull. INT-69. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 92 pp.

Forest Products Laboratory. 1987. Wood handbook: wood as an engineering material. Agric. Handb. 72. Washington, DC: U.S. Department of Agriculture, Forest Service. 466 pp.

Husch, B., C.I. Miller, and T.W. Beers. 1982. Forest mensuration. Edition Three. John Wiley & Sons. 402 pp.

Little, E.L. 1976. Southwestern trees: a guide to the native species of New Mexico and Arizona. Agric. Handb. 9. Washington, DC: U.S. Department of Agriculture, Forest Service. 109 pp.

Maingi, J.K., and P.F. Ffolliott. [This proceedings]. Specific gravity and estimated physical properties of Emory oak in Southeastern Arizona.

Neter, J., and W. Wasserman. 1974. Applied linear statistical models. Richard D. Irwin. 842 pp.

Sackett, S.S. 1980. Woody fuel particle size and specific gravity of Southwestern tree species. Res. Note RM-389. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 4 pp.

SAS Institute, Inc. 1989. SAS/STAT user's guide, version 6, fourth edition, volume 2. SAS Institute Inc., Cary, NC. 846 pp.

Van Hooser, D.D., R.A. O'Brien, and D.C. Collins. [In press]. New Mexico's forest resources. Resour. Bull. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

Whittaker, R.H. and W.A. Niering. 1975. Vegetation of the Santa Catalina Mountains, Arizona. V. Biomass, production, and diversity along the elevation gradient. Ecology 56(4):771-790.

Feral Pig Activity Associated with Coast Live Oak Regeneration on Santa Cruz Island, California[1]

Diann Peart and Duncan T. Patten[2]

Research begun in 1989 indicated that feral pig activity was positively associated with a decrease in woody species seedling density beneath the canopy of Coast Live oak (Quercus agrifolia) on Santa Cruz Island, California. Seedling density varied significantly between exclosures and control areas and was found to decrease with cumulative pig impact in the control plots. A five year drought in California led to a sharp decline in feral pig population, but with recent normal rainfall, pig impact is again increasing.

INTRODUCTION

The California landscape was once graced with an abundance of magnificent oaks (Quercus sp.), but vast numbers of these have been displaced by urban expansion and development (Rossi 1979). Concern has been expressed that the oaks which remain are no longer regenerating naturally (Griffin 1971). Regeneration studies on the mainland of California have traditionally been hampered by interference from deer, cattle, and various rodents as well as human activities and have focussed on the outplanting of seedlings. Current research on Santa Cruz Island, the largest of the California Channel Islands and a Nature Conservancy preserve, has proceeded in the absence of such factors and has focussed on the natural cycle of vegetation response to the removal of all introduced mammals with the exception of feral pigs (*Sus scrofa*).

My research objectives involve determining the extent to which feral pig activity impedes woody species seed germination and prevents seedling establishment on Santa Cruz Island, California. According to historical records on Santa Cruz Island, domestic pigs were introduced in 1852 and allowed to roam freely on what was for over a hundred years, a privately owned cattle ranch. Today a growing population of feral pigs presents a serious threat to the island's fragile ecosystems. Acorn mast provides up to 70% of the pig's seasonal diet with acorn consumption approaching 100 percent (Barrett 1979). Where feral pigs occur, their rooting and trampling in the leaf litter beneath the oaks is a significant barrier to woody species (particularly *Quercus*) regeneration.

Five years of severe drought, 1987 to 1992 (Gleick and Nash 1991:4), were interrupted by significant rainfall in March 1991, followed by additional rain in June, 1991. These events led to acorn production by the scrub oaks (*Quercus dumosa*) in the fall of 1991. The feral pig population on Santa Cruz Island, which had declined dramatically with the loss of its primary food resource, began recovering. Near normal rainfall levels recorded for the 1991-92 winter season coupled with a spring blossoming of the Coast Live oaks (*Q. agrifolia*), heralding fall mast production, suggest that pig impact can be expected to increase.

METHODS

At 10 sites (Figure 1), each beneath a mature Coast Live oak (*Q.agrifolia*) in the oak woodland community of the island's Central Valley, permanent exclosures (one per site, 36 m^2) were constructed in January 1989 to prevent pig access. A matching control plot allowing pig access was also delimited adjacent to each exclosure. Plot monitoring began in March, 1989, and has been conducted twice annually, usually in March and June. Total vegetation, herbaceous litter accumulation and oak litter accumulation were measured as percent cover. Exotic (non-native) plant species cover was derived as a relative percent of total vegetation cover. Woody species seedlings were counted, mapped and individually marked with survey flags. Seasonal rainfall was recorded for each sampling period.

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[1] Poster presented at the Symposium on Ecology and Management of Oak and Associated Woodlands: Perspectives in the Southwestern United States and Northern Mexico. Sierra Vista, Arizona, April 27-30 1992

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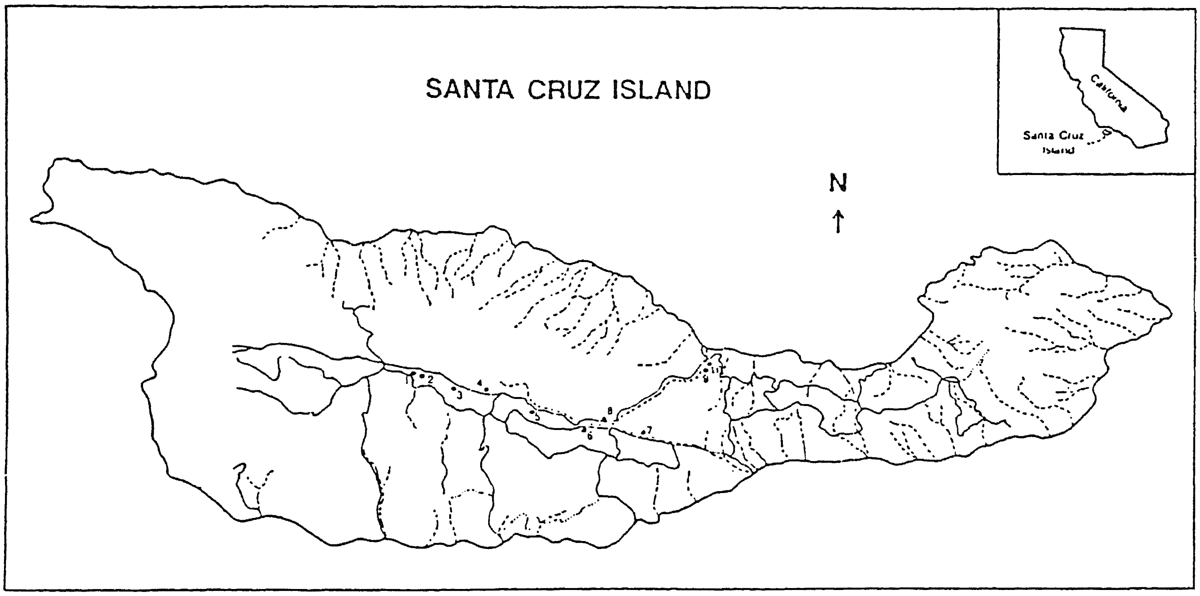

Figure 1. Santa Cruz Island, 35 km. off the southern coast of California. The ten research sites in this study are identified. Elevation ranges from 289 m. at site #1 to <1m. at site #10.

Pig impact (rooting, overturned rocks, trampling) was measured on a relative scale from 0 to 6, with 6 being 100 percent distubance of the surface in the plot. Cumulative pig impact was determined by averaging the impacts over the 8 sampling periods (1989-1992) included in this study.

Paired t-tests compared exclosures and control plots for total vegetation cover, oak and herbaceous litter accumulation, seedling density, cumulative pig impacts, and percent exotic species. Woody seedling density was regressed on cumulative pig impact for the exclosures and control plots.

RESULTS and DISCUSSION

This study was initiated shortly before the drought became a severe event in the western states. By the end of 1991, pig population had been reduced 75% from an estimated 3165 in 1988. The remaining pigs retreated into the deep coastal canyons and effectively vanished from the Central Valley's oak woodlands (Sterner 1990; Laughrin, pers. comm. 1992). During this period, 1989-1991, pig impact in the control plots declined (Figure 2). In 1992, pig impact increased in the control plots. Pig impact in March 1992 had diminished slightly in the control plots, perhaps as a result of a shift in their resource base to grassland insects.

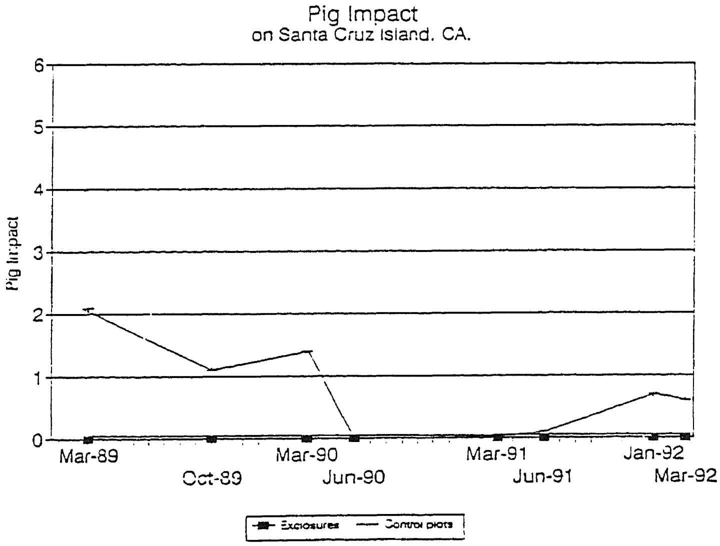

Figure 2. Pig impact in control plots and exclosures. Pig impact in the control plots is 2.2 (approximately 10%) in March 1989, zero in 1991 and rising again in 1992 following near normal rainfall. (Impact scale: 1=>5%; 2=5-25%; 3=25-50%; 4=50-75%; 5=75-95%; 6=95-100% disturbance of plot surface area).

Seedlings density in then exclosure and control plots regressed on cumulative pig impact (Figure 3.) indicated that 26% of the expected variation in seedling density can be accounted for by pig impact ($R^2=.26$, $n=20$, $p<.001$). Seedling density decreased as cumulative pig impact increases. Seedling density is also a function of rainfall (Figure 4.) In June,1990, both seedling density and pig impact were approximately zero. By January 1992, seedling density increased in both exclosures and control plots. However, pig impact also increased in the control plots in 1992 (Figure 2.), which may account for the lower seedling density in those plots. A paired t-test indicated that there was a significant difference between seedling density in the exclosures and control plots (*p* >.04; n=20), most likely as a result of increased pig impact in the control plots (Figure 2.). Rainfall in March 1991 (Figure 5) was followed by an increase in seedling density in October and by the following March (1992), seedling density had increased fourfold.

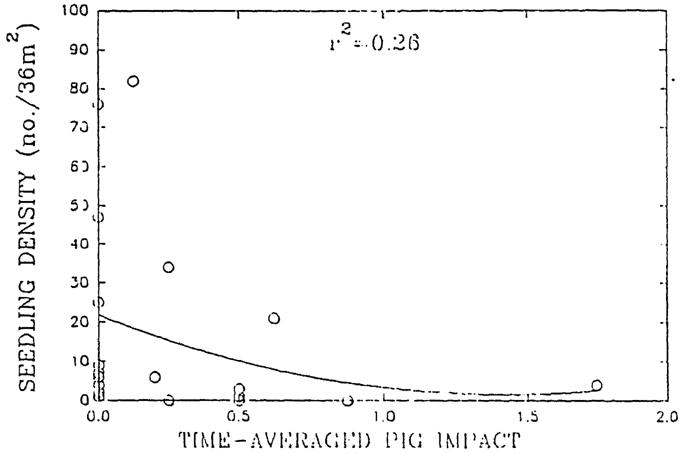

Figure 3. Woody seedling density as a function of cumulative pig impact, March 1992. Cumulative pig impact was derived by averaging the impact for 8 prior sampling periods and was then regressed upon March 1992 seedling density (R^2=.26; n=20).

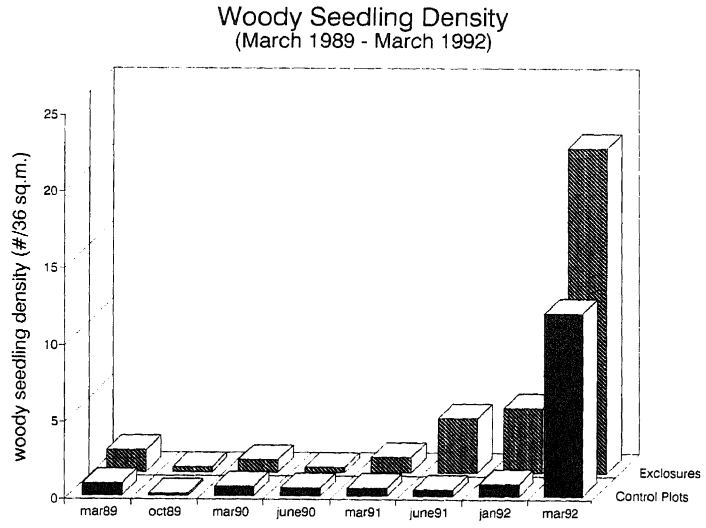

Figure 4. Average woody seedling density in exclosures and control plots March 1989 to March 1992

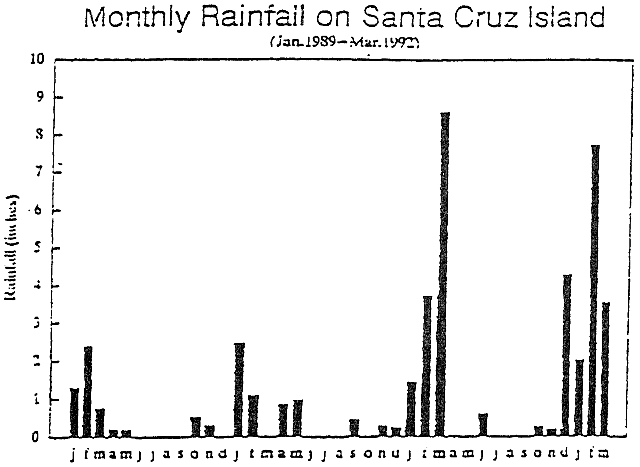

Figure 5. Monthly rainfall averages on Santa Cruz Island, California, January 1989 to March 1992.

CONCLUSIONS

Feral pigs have an important impact on woody plant seedling densities when their population is not suppressed by low food resources due to drought. However, other conditions also control this seedling density, such as rainfall events that trigger woody seed germination and the soil nutrient balance (which is also disturbed by pig impact). Feral pig impact in the control plots declined to zero in 1991 as the result of the drought, but with recent rainfall at normal levels, their impact is once again increasing.

LITERATURE CITED

Barrett, R. 1979 Mammals of California oak habitats--management implications.

Claremont,CA: USDA, FS, Pacific and Southwest Forest and Range Experiment Station, 275-291.

Gleick, P. and Nash, L. 1991 The societal and environmental costs of the continuing California drought. Berkeley, CA: Pacific Institute for Studies in Development, Environment and Security

Griffin., J 1971 Oak regeneration in the upper Carmel Valley, CA. Ecology 52(5(:862-868.

Laughrin, L. 1992 Santa Cruz Island Reserve manager, University of California at Santa Barbara, personal communication.

Singer, F. et al 1984 Effects of wild pig rooting in a deciduous forest. Journal of Wildlife Management, 48:464-473.

Sterner, J. 1990 Population characteristics, home range, and habitat use of feral pigs on Santa Cruz Island, CA. Masters, University of California at Berkeley.

Fire History in a Mexican Oak-Pine Woodland and Adjacent Montane Conifer Gallery Forest in Southeastern Arizona[1]

Thomas W. Swetnam, Christopher H. Baisan, Anthony C. Caprio, and Peter M. Brown[2]

Fire-scarred logs, snags, and trees were sampled within an oak-pine woodland and adjacent conifer-dominated gallery forest in Rhyolite Canyon, Chiricahua National Monument. Dendrochronological analysis of these fire-scarred samples documents a fire regime characterized by episodic surface fires that occurred at intervals of 1 to 38 years. The mean fire interval (MFI) for the entire study area was 3.9 years for fires scarring any tree and 13.2 years for fires scarring at least 25% of the sampled trees for the period A.D. 1620 to 1890. Based on the position of fire injuries within tree-rings and recent studies of cambial phenology, these fires occurred primarily between May and late July. Lower canyon areas dominated by woodland type vegetation sustained a reduced MFI (more frequent fires) during the latter portion of the 19th century. This reduced MFI may have been caused by shifts in Apache burning practices. Virtually no fire activity occurred in the conifer dominated central portion of the canyon during the 50-year period 1801-1851. We hypothesize that this 50-year hiatus in fire activity resulted from changes in fuel continuity due to flood and/or debris-flow events. Cessation of the episodic fire regime after 1890 is attributed to livestock grazing and associated reduction in the amount and continuity of surface fuels.

Based on modern patterns of lightning fire ignitions and the fire scar record, the oak-pine gallery forest in Rhyolite Canyon appears to have served as a conduit that allowed fire to spread across elevation gradients. We conclude that important sources of fire were the high elevation pine forests in the uplands above the head of the canyon and the low elevation grassland and woodland communities at and below the mouth of the canyon. Elimination of episodic fires has resulted in significant changes in community composition and structure as well as the amount and distribution of live and dead fuel. These changes, in addition to the existence of artificial management boundaries, will complicate planning and implementation of fire management programs. Nevertheless, the historical perspective offered by this study provides a baseline for assessing patterns of change and, perhaps, a model for desired future conditions.[3]

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[1] Paper presented at the symposium on the Ecology and Management of Oak and Associated Woodlands: Perspectives in the Southwestern United States and Northern Mexico. Sierra Vista, AZ, USA, April 27-30, 1992.

[2] Laboratory of Tree-Ring Research, University of Arizona, Tucson, Arizona, USA.

[3] For a more complete presentation and analysis of this data please refer to Swetnam et. al. 1989 and Swetnam et. al. 1991.

INTRODUCTION

Knowledge of fire regimes, including the frequency, areal extent, and intensity of past fires, is needed to evaluate and plan prescribed burning programs in wilderness and parks. There is widespread agreement among most forest scientists and land managers that fire is essential for the healthy functioning of forest and woodland ecosystems, and that this process should be reintroduced in wilderness and parks where it has been artificially excluded by humans. Fire regimes are, however, highly variable both spatially and temporally, even within forest types. Documentation of past fire regimes is therefore one of the first and most basic scientific inventories that is necessary to improve understanding of the fire process within specific management units (Kilgore 1987).

Few studies of fire history or fire effects in Madrean evergreen woodland have been conducted, but the presence and importance of fire within the various woodland community types has been noted (Leopold 1924; LeSueur 1945; Wallmo 1955; Marshall 1957, 1963; Moir 1980, 1982; Niering and Lowe 1984). Marshall (1963), surveying birds in the Mexican pine-oak woodlands, compared woodlands of Mexico to those in the United States and felt fire played a different role due to the differences in fire suppression policies at the time of his study. In Mexico, where fire suppression was minimal, he found the woodlands to be open with a dense grass understory. Across the border in the United States where fire suppression was sophisticated and generally effective, Marshall observed that woodlands were stunted, have heavy fuel accumulations, and little grass understory. Fires that do occur are often severe and may kill most of the overstory trees and understory plants.

This study documents more than three centuries of fire regime variations along an elevation gradient. The study area is of particular interest because of the transition along this gradient, from an open oak-pine woodland at the lower end through mixed-conifer forest to open pine forest at its upper terminus. We were able to reconstruct the fire regime along this gradient by sampling and dendrochronologically dating fire-scarred pines.

DESCRIPTION OF THE STUDY AREA

Chiricahua National Monument is located in southeastern Arizona, occupying a relatively low area at the north end of the Chiricahua Mountains. Elevations within the Monument range between 1,579 and 2,229 m (5,180 and 7,313 feet). Terrain is extremely rugged and is dissected by several large, steep-walled, canyons (Bonita, Rhyolite, and Jesse James) which drain to the west.

The study area includes Rhyolite Canyon, several side canyons, and the upland area between the head of Rhyolite and the adjacent watershed to the south. A few samples were also collected near the mouth of Surprise Canyon, a small watershed immediately to the north of Rhyolite Canyon. Rhyolite is the largest canyon within the monument and drains westward into the Sulfur Springs Valley. Streamflow is intermittent and the channel is well developed with a relatively broad, gravelly, boulder-strewn bottom at the monument headquarters.

Soils are shallow on the uplands, but relatively deep and stable in canyon bottoms. They are generally gravelly to moderately coarse and are derived from a substrate of rhyolitic tuff (Reeves 1976). Slopes are of varying degree and exposure, but aspects are predominately north or south. Aspects is especially important in determining species composition through the effects of insolation and evapotranspiration.

Vegetation of the study area is diverse, a consequence of a broad range of elevation, precipitation, temperature, topography, soil, and fire regimes. Plant species composition is strongly influenced by distinct regional plant communities located to the north, east, and south, leading to a high degree of biotic complexity not found at higher latitudes. Higher elevation, mesic montane conifer forests found within protected habitats in Chiricahua National Monument have northern affinities while lower elevation semi-desert grasslands have affinities to the east. Madrean evergreen oak woodland, comprising 60% to 65% of the vegetation cover in the monument, is strongly influenced by the Sierra Madre where the distributional center of oak woodland is located. The type within Rhyolite Canyon also has some affinities with more northern and western interior chaparral (Reeves 1976, Murray 1982).

Major tree species occurring in the study area are: *Pseudotsuga menziesii* (Douglas-fir), *Pinus ponderosa* (ponderosa pine), *P. leiophylla* var *chihuahuana* (chihuahua pine), *P. engelmannii* (apache pine), *P. discolor* (border pinon), *Cupressus arizonica* (Arizona cypress), *Quercus chrysolepis* var *palmeri* (canyon live oak), *Q. rugosa* (netleaf oak), *Q. hypoleucoides* (silver-leaf oak), *Q. emoryi* (emory oak), *Q. arizonica* (Arizona white oak), *Arbutus arizonica* (Arizona madrone), and *Juniperus deppeana* (alligator-bark juniper). Detailed descriptions of the vegetation within the monument can be found in Roseberry and Dole (1939), Moir (1975), Reeves (1976), and Murray (1982). Major plant associations are interior chaparral, semi-desert grassland, montane conifer forest, relict conifer forest, and Madrean evergreen woodland.

Climate of southeastern Arizona is semi-arid, characterized by low rainfall, relatively high temperature and evaporation, and low humidity. Precipitation is distinctly bimodal with wet winters and summers and a pronounced foresummer drought (April-June) and a less predictable fall drought. Summer rains in the form of thunderstorms occur from July to September with moist air usually flowing from the southeast. Winter storms from December to March are usually derived from frontal systems from the northwest (Sellers et al. 1985). Average temperatures for oak woodland stations in southeast Arizona are highest in late June and early July and lowest during January. Average minimum temperature for January is -0.2°C (31 °F) while average maximum is 14.7°C (56 °F). In July the average minimum and maximum temperatures are 17.4 and 32.8°C respectively (63 and 91 °F).

The fire season in southeastern Arizona occurs mainly in the late spring and early summer, prior to the inception of the "Arizona monsoon", and occasionally extends throughout the summer into October (Barrows 1978). The pre-monsoon season is a period of high temperature, low humidity, and dry vegetation. Weak storm cells sometimes develop in which virga and lightning are common. Lightning during this period often results in isolated or clustered ignitions that are associated with specific storm systems (Bock et al. 1976; Murray 1982).

METHODS

A chain saw was used to fell snags, section logs and stumps, and remove samples from living trees. Where possible, as an alternative to felling snags, wedge sections were removed from the face of the scar as described by Arno and Sneck (1977). Fifty-six cross sections or wedges were collected in this manner. Forty-five of these samples were from remnants (dead trees and logs) and eleven were from living trees. One additional sample, which had been previously collected, was obtained from Chiricahua National Monument.

Samples were sectioned with a band saw and sanded with a series of progressively finer sanding belts (40 to 320/400 grit) to prepare the surface. Cross sections were examined with a binocular microscope, and cross-dated as described by Stokes and Smiley (1968). Once the specimens had been successfully cross-dated, fire dates (determined from the fire scars) were recorded. The position of the scars within the rings, when discernable, was also noted to provide an estimate of the season of occurrence (Ahlstrand 1980; Barrett 1981; Dieterich and Swetnam 1984; Baisan and Swetnam 1990).

The fire scars were identified as one of the following types based on observations of relative positions within annual rings:

D - Dormant season. Fire scar occurred on the boundary of two rings, with latewood cells of the prior year on one side of the scar and earlywood cells of the next year on the other side of the scar. Because the fire season begins in the spring in southern Arizona, these scars were dated to the later year (that is, as spring rather than fall fires).

E - Earlywood. Fire scar occurred within earlywood cells of one annual ring. These types of scars were further sub-classified when possible into categories of **EE**, early-earlywood, occurring within the first one-third of the earlywood portion of the ring; **ME**, mid-earlywood, occurring in the second one-third of the earlywood; **LE**, late-earlywood, occurring in the last one-third of the earlywood. Earlywood scars that could not be sub-classified were simply given the generic classification of **E**, earlywood. Earlywood type scars were probably formed by fires occurring between May and July or early August.

L - Latewood. Fire scar occurred within the latewood cells of the ring. Latewood type fire scars were probably formed by fires occurring between July and the end of September.

Interpretations of the probable period when the different scar-types were produced are based on observations of cambial growth in the Santa Catalina Mountains (Fritts 1976) and current studies of cambial phenology in Rhyolite Canyon (Baisan and Swetnam in preparation).

RESULTS AND DISCUSSION

The use of dendrochronological dating methods allowed us to sample primarily logs and snags. Sampling of this remnant material might be considered a "salvage" of scientific information, since this material is continually decaying, and thus information on past forest ecosystems is becoming less available. Much of this dead woody material is present only because of fire suppression activity during the current century; under pre-settlement fire regimes it would have burned long ago. This material will be consumed and historic information irretrievably lost as prescription burning becomes more common.

Modern fire data

Chiricahua National Monument fire records document a dispersed ignition pattern and rather low overall ignition rate (1.5/yr.) (Jandrey 1975). Twenty six percent of recorded fires occurred within the Rhyolite watershed. Almost no ignitions in the modern record occurred within the canyon proper, leading to the conclusion that the majority of historic fires were ignited elsewhere and were able to spread into and within the drainage.

Comparison of recent versus past fire regimes and ignition sites must be interpreted in light of associated vegetation changes which may have occurred in the last 100 years. Changes have been noted in most vegetation types of southeastern Arizona (Leopold 1924; Marshall 1957, 1963; Hastings and Turner 1965; Reeves 1976; Bahre 1991) and are very apparent in oak woodlands, desert grasslands, and pine forest. General patterns are increased dominance of woody plants and a corresponding decrease in dominance of herb species. Alteration in the fuel matrix would certainly affect ignitions and spread of fire through the various vegetation types.

The fire-scar record

Analysis of the fire scarred samples provided a five-century long record of fire activity in this watershed from the earliest fire date in 1476 to the last in 1983. The mean fire interval (MFI) for fires that burned through extensive portions of Rhyolite Canyon was 13.2 years with a range of 1 to 31 years. In general, for the 1620 to 1801 period, the MFI estimates did not differ appreciably from the upper to the lower reaches of the canyon. After 1801, however, this pattern of episodic, canyon-wide fire changed dramatically. At this point a 50-year fire-free interval occurred in the mid and upper part of the main canyon (Fig. 1). Trees in the lower canyon continued to record fire activity with a MFI similar to the period prior to 1801.

After 1851, fires were recorded again by trees in the upper and middle portions of the canyon until 1886 when the last widespread fire was recorded. During this period the lower canyon continued under a largely separate fire regime characterized by a pronounced increase in fire frequency. Lower canyon trees recorded fires in 1852, 1856, 1859, 1867, 1873, and 1882 for a much reduced MFI of 6.0 years. Of these fires, only the fire of 1859 was recorded by trees sampled in other areas of the canyon. After the late 1880s few fires were recorded anywhere in the drainage.

The general synchrony of pre-1801 fire-scar dates within the canyon suggests that regardless of where a fire began, once in the canyon it tended to spread throughout large portions of the drainage. It is possible that some scars were caused by fires ignited separately at different points along the canyon, although the low ignition rate during the historic period suggests this was unlikely. Modern fire records indicate ridges and upland areas have been a source of lightning ignition in the recent past. It is probable that lightning fires from the higher elevations occasionally were able to burn downslope into the main canyon. Another ignition source may have been fires burning up from the grassland at the base of the mountains. Slightly higher fire frequencies

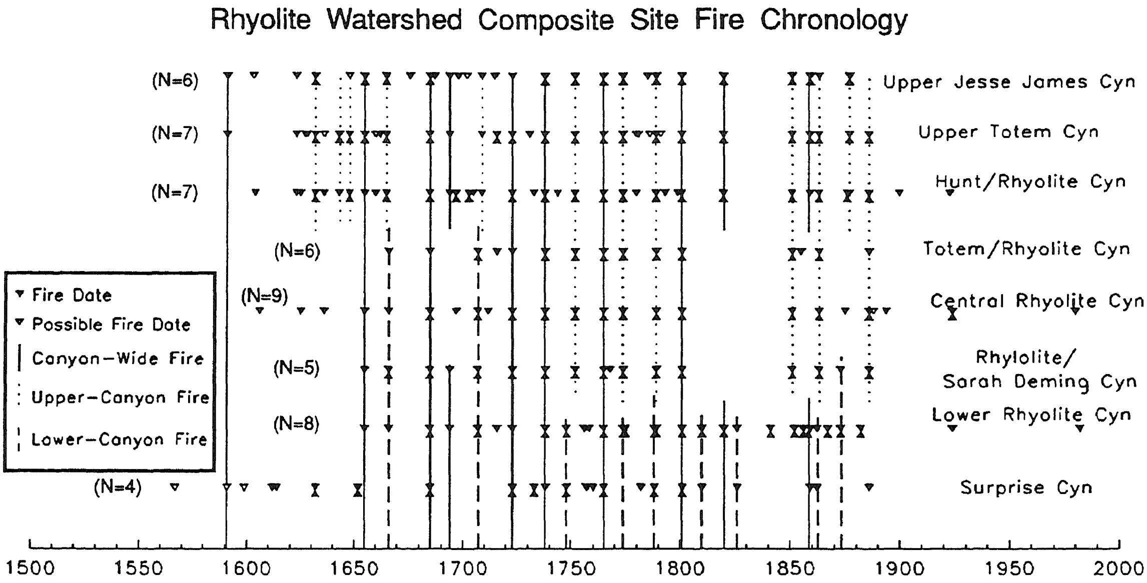

Figure 1. Fire chronology chart for the entire study area including Surprise Canyon and the upland area (upper Jesse James Canyon and upper Totem Canyon). Data are organized by groups of trees in relatively close proximity with the number of samples in each group shown in parenthesis. Canyon-wide fires as well as those affecting just the mouth of Rhyolite Canyon and the upland area are noted with a solid line, those which affected the upper watershed with a dotted line, while those affecting the lower canyon are shown with a dashed line.

recorded in both the upper and lower groups of trees as compared to the middle group suggest these were closer to areas of ignition and that not all fires were able to spread the length of the canyon system.

After 1801 this pattern changed. The subsequent 50-year hiatus in the scar record for trees in the upper and middle groups has not been observed in any other fire chronology from the southwest during the pre-1900 period. A possible explanation for this change in the fire regime may be related to a change in fuel continuity within the canyon. Before 1801, when fires were canyon-wide events, fuel continuity probably allowed fires to spread throughout the drainage. Fires recorded by trees at the mouth of the canyon after 1801 were not recorded on trees higher in the drainage and vice versa. Also, assuming fires were still ignited in the uplands, none appear to have been able to burn into the canyon bottom.

We hypothesize that a flood and/or debris flow event disrupted fire spread patterns after 1801. We have observed that large floods can almost completely scour vegetation from canyon bottoms in southeastern Arizona. For example, an October 1983 flood stripped vegetation from some riparian corridors in the Galiuro Mountains. Such an event could produce the fire regime changes we documented in Rhyolite Canyon. We are currently investigating pre 1900 flood history in Rhyolite Canyon through the analysis of flood-scarred trees (McCord 1990). Although 1866 is currently the oldest flood date documented in this manner, more thorough sampling may reveal additional, earlier, dates.

Increased fire frequency in the lower portion of Rhyolite Canyon after 1851 is especially suggestive of human influence. Bonita Canyon, the next major canyon north of Rhyolite, was historically used as a route of travel through the mountains by the Apache. In 1885, the Army established a camp close to the mouth of Bonita and Rhyolite specifically to control Apache use of this area (Baumler 1984). It is possible, therefore, that the increased Apache presence sometime in the mid to late 1800s may be related to with the increase in fire frequency. Similarly, the end of the fire regime in the late 1880s could be linked to the establishment of the Army camp, removal of the Apache and the advent of intensive grazing in the area. Pre-settlement episodic fire regimes in southwestern forests were usually eliminated at the time of intensive grazing, and one to several decades before effective fire suppression (Swetnam 1990; Baisan and Swetnam 1990; Savage and Swetnam 1990).

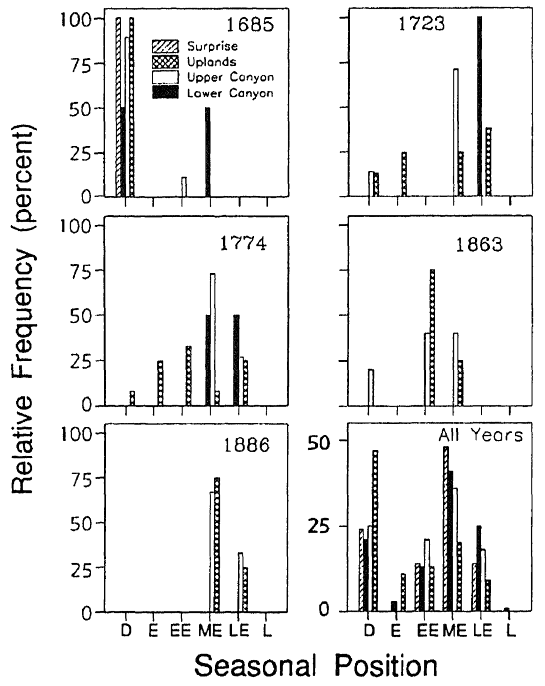

Figure 2. Histograms of the seasonal position of fire scars for various dates. Fires were predominantly early season with only occasional late season fires.

Intra-annual (seasonal) data were sorted by fire date and a series of histograms constructed for six major fire years between 1685 and 1886 (fig. 2). Most fires occurred within some portion of the earlywood, indicating that growing season fires from approximately May to August were most typical of pre-settlement fires. Distributions of scar position for some fires suggested specific seasonal timing for these events. For example, the fires of 1685, 1707, 1765, and 1801 appear to have occurred early in the growing season, perhaps during the month of May or June. The fires of 1723, 1789, 1851, 1863, and 1886 appear to have occurred well into the growing season, possibly as late as August or September.

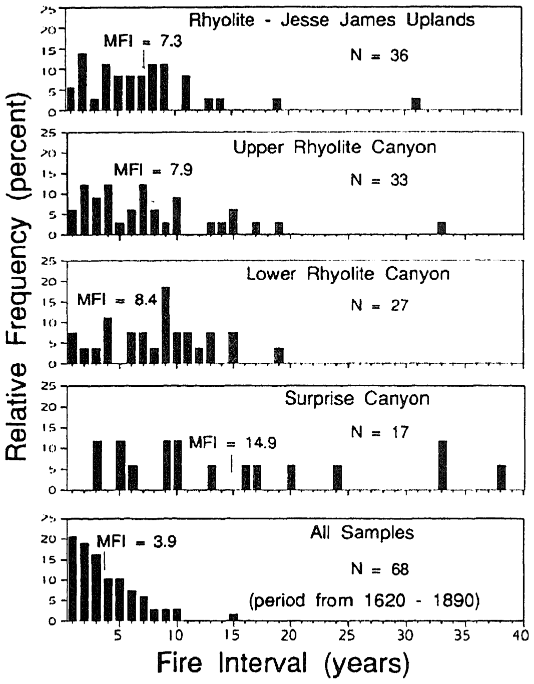

Figure 3. The distribution of fire intervals, all fires included, in various portions of the canyon system. *N* is the number of intervals. Note the general variability in relation to the mean interval. Such variability appears to have characterized pre-settlement fire regimes in the southwest.

Although MFI is often used to characterize fire regimes, it can be seen from figure three that a simple reporting of the mean interval masks the inherent variability of this disturbance process. Variability, itself, should also be recognized as an important characteristic. Additionally, when the area considered exceeds the average fire size the MFI ceases to have relevance for a specific point. Rather, it becomes a measure of the frequency of fire occurrence within an area.

SUMMARY

- Spreading fires, recurring at intervals of 1 to 19 years, were an integral component of the dynamics shaping the vegetation within Rhyolite Canyon and adjacent forested areas over at least the past five centuries.
- Fires occurred predominantly during the spring and early summer months.
- Many fires appear to have been large by today's standards, some burning throughout the drainage.
- Geomorphic processes (floods and debris flows) probably interacted with the fire regime within the Canyon.
- The fire regime influenced a variety of plant associations along an elevational gradient from grassland, oak-conifer woodland, montane conifer gallery forest, to upland pine forest.

CONCLUSIONS

Fire played a key role in shaping the diverse plant communities within the Rhyolite Canyon watershed of Chiricahua National Monument. Although three distinctly different community types occur along this drainage, the mean and range of fire intervals differed little among them. Given the evidence of frequent surface fires during pre-settlement times, the virtual cessation of these fires around the turn of the century, and the obvious accumulation of live and dead fuels in the canyon over the last 90 years, it is clear that profound changes in ecosystem composition and structure have occurred. Additionally, we hypothesize that floods and debris flows interacted with the fire regime by altering the fuel distribution.

These results provide a baseline and justification for management policy that acknowledges disturbance processes as fundamental attributes of natural communities, and seeks to reintroduce that process. Knowledge of fire seasonality and typical fire recurrence intervals, coupled with information derived from other studies on the response of species to fire, will aid in developing reconstructions of the pre-settlement composition and structure of these communities. These reconstructions may then be used to assess both the amount of change that occurred during the past century and to predict the probable effects of management actions.

ACKNOWLEDGEMENTS

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LITERATURE CITED

Ahlstrand, G.M. 1980. Fire history of a mixed-conifer forest in the Guadalupe Mountains National Park. In: Proceedings of the Fire History Workshop, Oct. 20-24, 1980, Tucson, Az. USDA Forest Service, General Technical Report RM-81:4-7.

Arno, S.F. and K.M. Sneck. 1977. A method for determining fire history in coniferous forests in the Mountain West. USDA Forest Service, General Technical Report INT-42. 28pp.

Bahre, C.J. 1985. Wildfire in southeastern Arizona between 1859 and 1890. *Desert Plants* 7(4):190-194.

- 1991. A Legacy of Change: Historic human impact on vegetation in the Arizona borderlands. U. of Arizona Press, Tucson. 231pp

Baisan, C.H. and T.W. Swetnam. 1990. Fire history on a desert mountain range: Rincon Mountain Wilderness, U.S.A. *Can. J. For. Res.* 20: 1559-1569.

Barrett, S.W. 1981. Relationship of Indian caused fires to the ecology of western Montana forests. M. Sc. Thesis. University of Montana, Missoula.

Barrows, J.S. 1978. Lightning fires in Southwestern forests. Final Report prepared by Colorado St. Univ. for Intermtn. For. and Range Exp. Stn., under cooperative agreement 16-568-CA with USDA Forest Service, Rocky Mtn. For. and Range Exp. Stn., Ft. Collins, Colo. 154 pp.

Baumler, M.F. 1984. The archaeology of Faraway Ranch, Arizona. Western Archaeology and Conservation Center, National Park Service. 194pp.

Bock, J.E., C.E. Bock and J.R. McKnight. 1976. A study of the effects of grassland fires at the research ranch in southeast Arizona. *Arizona Academy of Science* 11:49-57.

Dieterich, J.H. and T.W. Swetnam. 1984. Dendrochronology of a fire-scarred ponderosa pine. *Forest Science* 30(1):238-247.

Fritts, H.C. 1976. Tree Rings and Climate. Academic Press, London. 567 pp.

Hastings, J.R. and R.M. Turner. 1965. The Changing Mile: An Ecological Study of Vegetation Change with time in the Lower Mile of an Arid and Semiarid Region. University of Arizona Press, Tucson. 317pp.

Jandery, F. 1975. Chiricahua National Monument Fire History. Unpublished report on file at Chiricahua National Monument, 10 pp.

Kilgore, B.M. 1987. The role of fire in wilderness: A state-of-knowledge review. In: Proceedings - National Wilderness Research Conference: Issues, State-of-Knowledge, Future Directions., Fort Collins CO, July 23-26, 1985. R.C. Lucas, compiler, USDA Forest Service, General Technical Report INT-220:70-103.

Leopold, A. 1924. Grass, brush, and timber fire in southern Arizona. *Journal of Forestry* 22(6):1-10.

Lesueur, H. 1945. The ecology of the vegetation of Chihuahua, Mexico, north of parallel twenty-eight. Publ. 4521, University of Texas, Austin.

Marshall, J.T. 1957. Birds of the pine-oak woodland in southern Arizona and adjacent Mexico. Cooper Ornithological Society, *Pacific Coast Avifauna* 32:1-25.

- 1963. Fire and birds in the mountains of southern Arizona. *Tall Timbers Fire Ecology Conference* 2:135-141.

McCord, V.A.S. 1990. Augmenting flood frequency estimates using flood-scarred trees. Dissertation, University of Arizona, Tucson, Arizona.

Moir, W.H. 1975. Resource monitoring system (Chiricahua National Monument). Unpublished report on file at Chiricahua National Monument, 70 pp.

- 1980. Some questions about fire ecology in southwestern canyon woodlands. In: Proc. of the Fire History Workshop, Oct. 20-24, 1980, Tucson, AZ. USDA Forest Service, General Technical Report RM-81.

- 1982. Fire history of the High Chisos, Big Bend National Park, Texas. *Southwestern Naturalist* 27:87-98.

Murray, W.B. 1982. Fire Management Plan: Chiricahua National Monument. Unpublished report on file at Chiricahua National Monument, 52 pp.

Niering, W.A. and C.H. Lowe. 1984. Vegetation of the Catalina Mountains: community types and dynamics. *Vegetatio* 58:3-28.

Reeves, J. 1976. Vegetation and flora of Chiricahua National Monument, Cochise County, Arizona. MS Thesis, Arizona State University. 180 pp.

Roseberry, R.D. and N.E. Dole, Jr. 1939. The vegetation type survey of Chiricahua National Monument. U.S. Department of Interior, San Francisco, 42 pp. + map.

Savage, M. and T.W. Swetnam. 1990. Early 19th-century fire decline following sheep pasturing in a Navajo ponderosa pine forest. *Ecology* 71: 2374-2378.

Sellers, W.D., R.H. Hill and M. Sanderson-Rae. 1985. Arizona Climate. University of Arizona Press, Tucson. 143 pp.

Stokes, M.A. and T.L. Smiley. 1968. An Introduction to Tree-Ring Dating. University of Chicago Press, Chicago. 73 pp.

Swetnam, T.W. and J.H. Dieterich. 1985. Fire history of ponderosa pine forests in the Gila Wilderness, New Mexico. In: Proceedings Symposium and Workshop on Wilderness Fire; Nov. 15-18, 1983, Missoula, MT.

USDA Forest Service, General Technical Report INT-182:390-397.

Swetnam, T.W., C.H. Baisan, P.M. Brown, and A.C. Caprio. 1989. Fire history of Rhyolite Canyon, Chiricahua National Monument. Cooperative National Park Resources Studies Unit, University of Arizona, Tucson. Tech. Rep. No.32. 47pp.

Swetnam, T.W. 1990. Fire History and climate in the Southwestern United States. In: Proceedings of the Symposium on the Effects of Fire Management of Southwestern Natural Resources, Nov 15-17, 1988, Tucson Az. USDA Gen. Tech. Rep. RM 191. P 6-17.

Swetnam, T.W., C.H. Baisan, A.C. Caprio, V.A.S. McCord, and P.M. Brown. 1991. Fire and flood in a canyon woodland: The effects of floods and debris flows on the past fire regime of Rhyolite Canyon, Chiricahua National Monument. Final report to the National Park Service, on file at the Laboratory of Tree-ring Research, University of Arizona, Tucson.

Wallmo, O.C. 1955. Vegetation of the Huachuca Mountains, Arizona. *American Midland Naturalist* 54:466-480.

Coppice Thinning of Emory Oak Sprouts: Effects on Growth, Yield, Harvesting Cycles[1]

Ramzi Touchan, Duane A. Bennett, and Peter F. Ffolliott[2]

Abstract.–Effects of stump diameter, coppice thinning treatments, and age of sprouts at the time of thinning are described in terms of growth and yield of Emory oak (*Quercus emoryi*) sprouts over a 5 year period. Growth and yield of residual sprouts depend largely upon the number of sprouts left after thinning, and the age of the sprouts at thinning. Effects of stump diameter were inconclusive. Harvesting cycles for fuelwood might be reduced through proper timing of coppice thinning treatments.

INTRODUCTION

Emory oak is a fuelwood resource for people in southeastern Arizona and northern Sonora, Mexico. To supply an enlarging population in the region with fuelwood and manage Emory oak under a sustained yield basis, silvicultural studies have been initiated in the area.

However, basic information about effects of coppice thinning on growth and yield has been lacking. Coppice thinning, if properly applied, could maximize volume and shorten harvesting cycles of Emory oak sprouts. The potential importance of coppice thinning encouraged the authors to investigate the effects of coppice thinning on the growth and yield of Emory oak sprouts.

DESCRIPTION OF STUDY

The objectives of this study were to determine the effects of stump diameter, coppice thinning treatments, and age of sprouts at the time of thinning on growth and yield over a 5-year period; and determine harvesting cycles of Emory oak sprouts in southeastern Arizona.

Study Area

The study area was located in the San Rafael Valley of southeastern Arizona. Elevation ranges from 5,200 feet in the southeast to 6,000 feet in the northeast. Slopes vary from 5 to 10 percent, with a south-facing aspect. Soils are deep, moderately fine to very fine textured, on nearly level to steep slopes on dissected alluvial fan surfaces and valley slopes. The soils, formed in old alluvium from mixed sedimentary and igneous rocks, are more than 60 inches deep.

Southeastern Arizona receives its precipitation in winter storm patterns from the Pacific Ocean and summer thunderstorms from the Gulf of Mexico. Most rainfall occurs in July and August. Records from the Coronado National Monument, near the study area, indicate that the mean annual precipitation for the general area is 20.5 inches.

The study area, found in the *Quercus emoryi* / *Bouteloua curtipendula* habitat, is dominated by Emory oak. However, the area also contains Arizona white oak (*Quercus arizonica*), alligator juniper (*Juniperus deppeana*), and Mexican pinyon pine (*Pinus cembroides*). There also is a variety of perennial grasses on the area, including *Eragrostis, Aristida, Avena, Bouteloua, Bromus, Agrostis, Festuca,* and *Tridens*.

Field Procedure

Five sites were delineated in the study area, treated by coppice thinning, and initially sampled in 1985 (Bennett, 1990). These sites had been harvested in different years, beginning in 1977, with one site harvested a year through 1981. All sites, similar in terms of physiography, were located within 1-mile of each other. On each site, stumps of previously harvested trees were selected randomly, grouped by stump diameter (4, 6, 8, and 10 inches), and assigned a coppice thinning treatment. Each stump, therefore, was considered a primary sampling unit.

Coppice thinning treatments, applied to the residual sprouts in December 1984 through February 1985 (Bennett 1990), involved thinning sprouts on the stumps, leaving 1, 2, or 3 of the largest and most vigorous sprouts as residuals. A control was included in the study to determine unthinned sprout growth patterns. Each treatment combination was replicated 10 times. After coppice thinning had been applied, the diameter at root collar (DRC) and total height of the residual sprouts were measured after one growing season to determine first year growth patterns (Bennett 1990).

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Five years after thinning, DRC and total height of the residual sprouts were remeasured. DRC and total height of ingrowth sprouts, those that grew into the 0.1 inch DRC class during the growth period, also were measured.

Analytical Methods

Analytical methods included estimation of sprout volume and determination of growth and yield. Sprout volume was calculated from modifications of Chojnacky's volume equations (Bennett 1990, Chojnacky 1988). Net growth was the volume increment based on initial tree volume, plus ingrowth (after mortality had been deducted). Yield, the total volume of residual sprouts, was determined by summation of volume for all sprouts on a stump.

Analysis of variance was used to determine if there were significant differences in net growth and yield among coppice thinning treatments. The level of significance for the tests was 0.10. Because there was an unequal number of sample units, a general linear model procedure available in SAS (PROC GLM) was used to estimate means and sums of squares. This procedure eliminated the problem of unbalanced data in the analysis (SAS 1985).

A test for homogeneity of variance was made while conducting analyses of variance. The test showed that the variances of different samples were unequal. Therefore, weighted least squares (WLS) was used in the analysis of variance (Draper and Smith 1981). Pairs of least square means were compared with a t-test.

RESULTS

Stump Diameters

Stump diameter generally did not consistently affect net growth and yield. Bennett (1990) also found stump diameters had no impact on sprout growth in the first year after the coppice thinning treatments.

Number of Residual Sprouts

Net growth and yield were affected by the number of residual sprouts left after coppice treatment. Net growth was lower for 1 residual sprout than the other thinning levels at 4 years, but had increased to the level of the other treatments by 8 years. Yield for 1 residual sprout remained lower than the yield for other treatments regardless of time elapsed.

Age of Sprouts

Age of sprouts affected net growth and yield. The interaction between age of sprouts and number of residual sprouts was significant, but interaction was not significant between age of sprouts and stump diameter. Interaction among age of sprouts, stump diameters, and number of residual sprouts also was not significant.

Eight-year-old sprouts had the highest net growth with the 1 and 2 residual sprouts treatment. However, eight-year-old sprouts had the highest yield with all treatments. There was no difference between sprout age 6 and 7 years in terms of net growth and yield.

DISCUSSION

Effects of stump diameter on the subsequent growth and yield of sprouts were inconclusive. It is anticipated that fuelwood cutters will have a tendency to harvest larger trees. On one hand, larger trees are more likely to have heart rot; therefore, removal of larger trees could result in a reduction of disease in the oak woodlands. On the other hand, harvesting larger trees also tends to eliminate seed producing trees.

Growth of residual sprouts depends largely upon the number of sprouts left after thinning. Net growth and yield were lowest for the 1 residual sprout class, with the exception of net growth for the 8-year-old sprouts. There were no differences in net growth between 1, 2, or 3 residuals sprout treatments and the unthinned controls.

Touchan (1991) found that for individual sprouts at age 8 years, mean annual growth per sprout increased as the number of residual sprouts per stump decreased. It is recommended, therefore, that 1 residual sprout be left when thinning sprouts. With 1 residual, growth will be concentrated on a single stem, and the stem will reach a desired diameter in a shorter period of time. For a fuelwood cutter, a single large sprout translates into reduced labor in harvesting.

It also might allow fuelwood cutters to harvest an area more frequently.

Age of the sprouts at the time of thinning affects growth. If sprouts are thinned too soon, resprouting will occur, reducing the effectiveness of thinning greatly. When thinning is delayed too long, potential growth will be lost to competition and mortality. Based on an increase in the mortality of the control sprouts in the 6th year, it is recommended that thinning be conducted in the 5th-year after initial fuelwood harvesting.

HARVESTING CYCLES

Proper timing of coppice thinning might reduce harvesting cycles of Emory oak sprouts, if a harvesting cycle is based on attainment of a specified diameter. It was observed that the 1, 2, or 3 residual sprouts measured in 1990 were almost 4 to 5 inches in DRC, indicating that the thinned sprouts were approaching the usable size classes. Regardless of specified diameters, which is the criteria for harvesting, thinned coppice sprouts should be available for harvest before their unthinned counterparts, allowing more frequent harvesting cycles.

In light of the above, the following scenario might serve as a preliminary guide to managers who are planning fuelwood harvesting of Emory oak:

0 years:	Growth of sprouts begins with harvesting of original trees. If the stand was harvested in the spring, new sprouts can appear by fall.
5 years:	Thin clumps of sprouts to the largest and most vigorous residual. Sprouts should be thinned at 5 years. Delayed thinning can reduce diameter growth in the residual sprout. More than 1 residual can be left (data collected in this study showed no differences in the volume growth per stump when 2 or more residual sprouts were left). However, since more sprouts are competing for nutrients, water, and sunlight, growth per sprout in the clump will be less, resulting in reduced diameter growth and likely postponement of harvest.
Harvest: time:	Trees can be harvested after they reach a time specified diameter. A diameter of 6 to 8 inches DRC should be achievable in 20 to 30 years after the coppice thinning treatment.

CONCLUSIONS

Effects of stump diameter on growth and yield of Emory oak were inconclusive. The number of residual sprouts affected growth. However, net growth and yield were lowest for stumps with 1 residual sprouts except for net growth on the 8-year-old sprouts. Here, there were no differences in net growth between 1, 2, or 3 residual sprouts and the unthinned controls. It is recommended that 1 residual sprout be left when thinning sprouts. Age of the sprouts at the time of thinning greatly affected growth and yield estimates.

There was an increase in mortality of the control sprouts in the 6th year. It is recommended, therefore, that thinning be conducted in the 5th year after fuelwood harvesting. Proper timing of thinning also might reduce the harvesting cycles of Emory oak sprouts, if harvesting cycles are based on achievement of a specified diameter.

Emory oak regeneration patterns should be monitored for a longer period of time to further refine these recommendations.

LITERATURE CITED

Bennett, D.A. 1990. First year of thinning coppice on *Quercus Emoryi* in southeastern Arizona. Master Thesis, 50 p. University of Arizona, Tucson, Arizona, 50 p.

Chojnacky, D.C. 1988. Juniper, pinyon, oak, and mesquite volume equations for Arizona. USDA Forest Service, Research Paper INT-391, 11 p. Intermountain Research Station, Ogden, Utah.

Draper N. R. and H. Smith. 1981. Applied regression analysis 709 p. John Wiley and Sons, New York.

SAS Institute Inc.1985. SAS User's guide: statistics 956 p. SAS Institute Inc., Cary, North Carolina.

Touchan, R. 1991. Effects of coppice thinning on the growth and yield of Emory oak sprouts in southeastern Arizona. PhD Dissertation, 130 p. University of Arizona, Tucson, Arizona.

Selection of Seedlings During Oak Woodland Restoration[1]

Thomas A. Scott and Nanette L. Pratini[2]

A study was done of the power of seedling height, growth rate, and leaf number to predict subsequent growth in the Engelmann oak (Quercus engelmannii), a white oak endemic to southern California. Data was collected during four growing seasons from three field-planted experiments and one container-grown greenhouse site. Rank correlations and regressions were performed. Sub-groups were subjected to different treatments, but treatments did not change over time. Initial heights, within-year growth rates, and leaf numbers of individual one-year old seedlings were poor predictors of seedling height and leaf number after planting, especially in later years. Correlations between seedling measurements between one year and the next generally increased with age. Individual variation in growth rates was high within treatment groups, suggesting the presence of acorn-related differences despite a single-tree seed source for two of the four experiments. Greenhouse seedlings, grown under uniform conditions, also showed first-year variability. The implications for restoration plantings include planting sufficient numbers to overcome seedling variability rather than choosing seedlings based on apparent vigor, and delaying thinning until at least the fourth year.

INTRODUCTION

In current efforts to restore southwestern ecosystems, the selection of seed and seedling stock is a major consideration. Because oak woodland restoration in the region is in a discovery phase, there are no specific selection criteria and relatively few protocols in choosing seedlings for planting. Nevertheless, variation in oak seedling growth can have a pronounced effect on the cost and long-term success of projects. Given the increased emphasis on ecological restoration in woodland management, there is a strong need to develop criteria and objectives for proper selection of seedling number, quality, size, age, and vigor.

In the course of initial experiments on oak restoration techniques, considerable variability in seedling growth was found which were poorly explained with between-group comparisons. Even when statistics (typically tests of treatment effect) showed significant differences between groups, there were many cases where individual variation in growth rates caused wide shifts in annual seedling-rankings by height and leaf number. These observations led us to re-examine our results in order to describe: (1) how variation in the growth rates of individual oak seedlings could influence the size and success of saplings in restoration projects, and (2) how this variation should be managed during seedling selection.

This paper examines whether early patterns of above-ground growth can be used to predict the ultimate size and success of oak seedlings. Root morphology is one of the best estimators of future growth (Johnson *et al* 1986, Ruehle and Kormanik 1986, Webb and von Althen 1979), but the manipulations necessary to see lateral branching (except in bare root planting) are typically more than the time and logistics of restoration will allow. Pre-selection of acorns by size and quality has been shown to improve growth potential (Aissa 1983, Farmer 1980, and Tecklin and McCreary 1991)), but acorn availability often limits selectivity. In most restoration projects, the opportunity to select acorns or examine roots may be limited, leaving shoot characteristics as the primary means of seedling selection. Above-ground indicators of future growth used by researchers include stem height and diameter (Stroempl 1985, Johnson *et al* 1986). Height at the time of planting (typically 1 year) is frequently used because it is quick (often visual) to estimate. However, the power and efficiency of this indicator have not been examined for any southwestern oak species. Our main objective was to examine between-year correlations in annual growth of oak seedlings, defining the ability of within-year growth to predict subsequent growth rates.

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[1] Poster presented at the Symposium on Ecology and Management of Oak and Associated Woodlands: Perspectives in the Southwest United States and Northern Mexico, Sierra Vista, Arizona, April 27-30, 1992.

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Figure 1. Engelmann oak (*Quercus engelmannii*)
Photograph by Tom Scott.

The Engelmann oak (*Quercus engelmannii*) (Figure 1) is endemic to southern California, with one of the smallest distributions (c. 14,500 ha of woodland) of any oak tree in North America. Considered a sensitive resource under the California Environmental Quality Act (CEQA), Englemann oaks and are often planted in restoration and mitigation projects. Although they occur in the Mediterranean climates of southern California, Englemann oaks are actually the northwestern-most representative of a closely related group of sub-tropical white oaks (Scott 1990). This subdivision of the genus includes species such as the Mexican blue oak (*Quercus oblongifolia*) and Arizona white oak (*Q. arizonica).*

METHODS

The data for these analyses were taken from one greenhouse and three field experiments on oak seedling growth and restoration techniques. A detailed description of treatments and results of these experiments will be reported in another paper (Scott and Pratini in prep.), but the treatments can be summarized as: (1) acorns planted with sterilized soil (aggregated or mixed with sand) or natural woodland (mycorrhizal) soil (aggregated or mixed with sand) in a greenhouse (n = 80), (2) acorns planted in field plots with and without amendments of woodland (mycorrhizal) soil (n = 112), (3) seedlings planted in field plots with and without amendments of woodland (mycorrhizal) soil (n = 60), and (4) seedlings planted in field plots under different levels of irrigation (including no irrigation)(n = 106). These experiment are hereafter referred to as EX1, EX2, EX3, and EX4, respectively, in the text.

Seedling height (ground to highest bud or leaf primordia) was measured and leaves were counted on a monthly basis. Only the annual (end of growing season) data is reported in this paper. Transplanted seedlings were measured in their pots before they were placed in the ground. Leaves of the oaks planted as acorns were counted monthly until they reached 100 leaves or more. Unless stated otherwise, all comparisons were made within a treatment group or within a comparison group. Spearman rank-correlation tests were used to examine within-group changes in ranking based on height and leaf number. Absolute growth (hereafter referred to as height) and the growth that occurred during each successive year (referred to as within-year growth) were used in seedling rankings. Parametric regressions were used to examine the influence of height and within-year growth measurements on subsequent measurements.

Acorns for EX1 and EX2 were taken from the same tree (1988) at Camp Pendleton, California; the seedlings used in EX3 were grown from acorns collected from several trees at the same location. The seedlings used in EX4 were from acorns collected from trees throughout the range of the Engelmann oak. Acorns were germinated at approximately 15° C (ground storage) in plastic bags with a combination of moistened peat and vermiculite.

The germinated acorns ($1<x<20$ mm of exposed radicle growth) in EX1 were planted (November 1988) and grown for two summers (1989 and 1990) in 1-gallon (9 x 9 x 40 cm) tree-pots at a greenhouse at South Coast Research and Extension Center (SCREC), Orange County, California. These seedlings were then (November 1990) moved to a greenhouse at the University of California, Riverside. They were maintained at 20° to 3o° C and 25% to 50% humidity. All pots were watered to saturation on a weekly basis. Germinated acorns in EX2 were planted into field plots (6 m between rows and 1.5 m between acorns in rows) in fall 1988 at SCREC and irrigated with 1-gallon/hr emitters (all seedlings were attached to the same water line). The irrigation schedule was set by California Irrigation Management Information System (CIMIS) (Snyder *et al.* 1985) evapotransporation rates adapted from citrus crops. The amount of water varied from 0.0 to 0.0 gal/week/seedling across seasons. The field where planting occurred was deep alluvial soil which had been used for approximately 20 yrs as an avocado orchard. These trees were cleared in 1983 and barley was grown from 1983 to 1988 to remove herbicide residues. Weed control after oak planting was achieved by disking between rows and by hoeing and hand-pulling around the seedlings.

The seedlings in EX3 and EX4 came from acorns germinated in 1987 and transferred to 1-gallon pots in 1988 (spring). These trees were transplanted into field plots (6m between rows and 3 m between seedlings) in the fall of

Table 1. Spearman rank-correlations of between-year comparisons of oak seedling height in four experiments.

Experiment	Year 1 to Year 2	Year 2 to Year 3	Year 3 to Year 4	Year 1 to Year 3	Year 1 to Year 4
.lm3					
One (all)	0.19	0.65		0.19	
treat. A	-0.04	0.59		-0.21	
treat. B	-0.55	0.34		-0.12	
treat. C	0.11	0.66		-0.04	
treat. D	0.45	0.59		0.29	
Two (all)	0.70	0.91		0.69	
treatment	0.60	0.88		0.56	
comparison	0.56	0.86		0.61	
Three (all)	0.20	0.82	0.93	-0.04	-0.12
treatment	0.09	0.74	0.91	-0.21	-0.15
comparison	0.27	0.81	0.94	-0.03	-0.21
Four (all)	0.32	0.77	0.91	0.17	0.10
treat. A	0.59	0.43	0.88	0.23	-0.22
treat. B	0.10	0.78	0.83	0.29	-0.06
treat. C	0.39	0.88	0.83	0.43	0.26
treat. D	0.12	0.63	0.90	0.11	0.09

1988. The seedlings in EX3 were irrigated on the same line and in the same manner described for the acorns. Seedlings in EX4 were irrigated but the levels were set at 60, 80, 100, and 120% of the calculated CIMIS for the other experiments.

RESULTS

Change in height rankings from first to second year. First-year height ranking was a poor predictor of rank in subsequent years (Table 1). In EX3, seedlings rose or fell an average of 10 ranks (9.9 ± 1.1 [SE]). Eight of the top ten seedlings in first-year height dropped out of the top ten in the second year heights; in some cases dropping back 21 ranks.

The change in ranking becomes more striking if the percent increase in height (second-year growth/first-year height) is substituted for second-year height. All of the top ten seedlings in the first year are replaced by seedlings from the bottom 15 ranks. Top seedlings dropped and lower seedlings gained an average of 11 ± 1.1(SE) ranks from first to second year in percent increase growth. Similar patterns occurred in the other three experiments.

Stabilization in height ranking after the second year. Rankings began to stabilize after the second year, allowing better accuracy in predicting seedling ranking. That is, there was an annual increase in Spearman rank- correlation r-values of approximately 0.30 in each experiment (Figure 2). By the fourth year, the largest seedlings tended to retain their rankings and few of the smaller seedlings experienced growth bursts. However, first- year height, compared with either height or percent increase, remained a poor predictor of seedling ranking in the third and fourth year (Table 1) in all experiments.

Regressions of height and annual growth rate. As in the case of the rank-correlations, first-year height (cm) was a poor predictor of second-, third-, and fourth-year height (Table 2). Since within-year growth adds a progressively smaller percent increase to absolute heights, r-values of between-year regressions increased with each year as expected.

Within-year growth in the second and third year (cm) were also poor predictors of subsequent-year growth. In most cases, r-values improved in second- to third-year comparisons (Table 2), but almost all r-values were extremely low and increases were biologically inconsequential despite statistical significance.

In nearly all treatments and comparison groups, the coefficient of variation (standard deviation/mean) of heights increased from the first to second year but began to stabilize between the second and third year. Although

Figure 2.

INCREASE IN BETWEEN-YEAR CORRELATIONS
OF OAK SEEDLING HEIGHTS

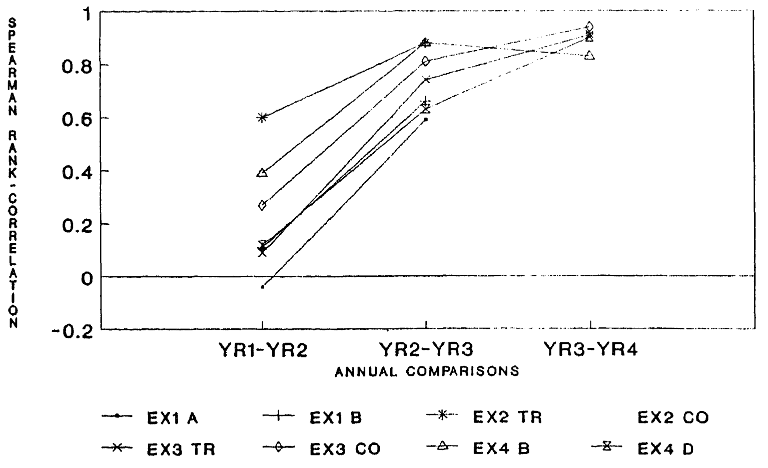

Table 2. Regressions of first year growth to subsequent years's growth.

	r^2 values for Annual Growth		
Experiment	Year 1 to Year 2	Year 2 to Year 3	Year 1 to Year 3
One			
treat. A	0.06	0.14	0.02
treat. B	0.43	0.08	0.00
treat. C	0.00	0.04	0.16
treat. D	0.08	0.00	0.00
Two			
treatment	0.08	0.18**	0.02
comparison	0.15**	0.41**	0.23*
Three			
treatment	0.00	0.08	0.13*
comparison	0.01	0.36**	0.02
Four (all)			
treat. A	0.01	0.00	0.00
treat. B	0.08	0.44**	0.06
treat. C	0.00	0.04	0.07
treat. D	0.00	0.04	0.05

*Significant level of $P < 0.05$
**Significant level of $P < 0.01$

much of this stabilization is attributable to the decreasing contribution of annual growth to total height, it still provides an indication that seedling growth becomes less variable after the second year.

Leaf Count as a Predictor of Seedling Growth. Leaf counts followed the same pattern observed in the analyses of height and growth rates. That is, first-year leaf count was a poor predictor of subsequent counts. Furthermore, leaf counts were also poor predictors of seedling height in subsequent years.

DISCUSSION

Individual variation in seedling growth, particularly in field plots, is expected in horticultural experiments because no experiment can deliver uniformity across individual plantings. Our observations of temporal changes in growth rates of individual seedlings, however, suggest a complex interaction between the intrinsic growth pattern of a seedling and its environment. Because we subjected these seedlings to similar treatments and conditions, we speculate that much of this variation may be attributed to acorn differences, or more specifically, the interaction of acorn variation with soil, water, and climatic conditions. Rice *et al* (1991) have shown some phenotypic variation attributable to the interaction of acorns with environmental conditions, but the area remains ripe for investigation. We observed shoot emergence two years after planting acorns, suggesting that acorns and radicles can remain viable and influence above-ground growth for long periods of time. Griggs (1986) found that seedlings suffered herbivory and resprouted up to four times in natural settings, providing circumstantial evidence of the long-term influence of acorns on seedling growth.

The temporal variation we observed in seedling growth rates lasts into the second growing season (approximately two years after germination). At that time, our seedlings started to establish a more predictable pattern of growth. For Engelmann oaks, and possibly other species, the potential growth of seedlings in relation to other members of its cohort could be measured in this second year. Until at least the second year, variation in growth rates can swamp subtle treatment effects in experiments and mask the long-term growth potential of oak seedlings in restoration projects.

Based on our data, thinning small seedlings before the third or fourth year of a restoration project could actually reduce the average growth rate of the restoration site. Under these circumstances it would be better to design planting sites so that thinning is either unnecessary or can wait until after the fourth year. At present, we believe that height after the fourth year is a reasonably strong predictor of future growth, but we will have to follow the trees for many years to be certain.

Following the same argument, the selection of one-year-old seedlings by size or leaf number does not necessarily guarantee the best cohort for a restoration project. The best way to address the inherent variability in seedling growth rates may be to numerically overcome the problem by planting a high number of seedlings. Our results suggest that concentrating efforts on a small number of seedlings could still produce a failure or low rate of restoration because the number of successful seedlings may be tied to the proportion of suitable acorns rather than the effort expended per acorn. There is always a trade-off between the number of seedlings relative to the effort given each seedling; however, planting high numbers of seedlings increases the chance that fast growing seedlings will find safe sites (Harper 1977).

Since the ultimate goal of a restoration project is to produce a viable woodland, then the most prudent strategy may be to plant high numbers of acorns (or seedlings) to increase the chances of maintaining the genetic variability of the populations. This variability, while poorly understood (Millar *et al* 1990), may help to protect the viability of the woodland over both ecological and evolutionary time.

The authors wish to aknowledge the assistance of Robert McKernan and the staff of SCREC in planting and maintaining the seedlings. Doug McCreary and Ursula Schuch made several helpful comments on an earlier version of this paper. Funding for this study was provided by the University of California Integrated Hardwood Range Management Program.

LITERATURE CITED

Aissa, D. 1983. Study on the germination of seeds of the holly oak (*Quercus ilex* L.): 1. Effect of the producer tree and the size of seeds. Rev. Cytol. Biol. Veg. Bot. 6:5-14.

Farmer, R.E. 1980. Comparative analysis of first-year growth in six deciduous tree species. Canadian Journal of Forest Research 10:35-41.

Griggs, F. T. 1986. The ecological setting for the natural regeneration of Engelmann oak (*Quercus engelmannii* Greene) on the Santa Rosa Plateau, Riverside County, Califonia. in Plumb, T. R. and Pillsbury, N. H., Proceedings of the symposium on multiple-use of California's hardwood resources, U.S. Forest Service Pacific Southwest Experiment Station, Gen. Tech. Report PSW-100.

Harper, J. L. 1977. Population Biology of Plants, Academic Press, New York, New York.

Johnson, P. S., Dale, C. D., Davidson, K. R., and Law, J. R. 1986. Planting northern red oak in the Missouri Ozarks: a prescription. Northern Journal of Applied Forestry 3:66-68.

Millar, C. I., Delany, D. L., and Riggs, L. A. 1990. Genetic variation in California oaks. Fremontia 18:20-21.

Rice, K. J., Gordon, D. R., Hardison, J. L., and Welker, J. M. 1991. Interspecific phenotypic and ecological genetics of blue oaks (*Quercus douglasii* Hook & Arn.). Pp. 59-63 in Standiford, R. B. (ed.), Proceedings of the symposium on oak woodland and hardwood rangeland management. US Forest Service Pacific Southwest Experiment Station, Gen. Tech. Report PSW-126, Pp. 376.

Stroempl, G. 1985. Grading northern red oak planting stock. Tree Planter Notes 36:15-18.

Synder, R., Henderson, D. W., Pruitt, W. O., and Dong, A. 1985. California Irrigation Management System Final Report. Unpublished report, Univ. of Calif. Dept. Land, Air, and Water Resources Papers 10013-A, Davis Calif.

Tecklin, J., and McCreary, D. 1991. Acorn size as a factor in early seedling growth in blue oaks. Pp. 48-53 in Standiford, R. B. (ed.), Proceedings of the symposium on oak woodland and hardwood rangeland management. US Forest Service Pacific Southwest Experiment Station, Gen. Tech. Report PSW-126, Pp. 376.

Quantifying Wildlife Habitats Within Gambel Oak/ Forest/Woodland Vegetation Associations In Arizona[1]

William H. Kruse[2]

Abstract.–Quantifying different phenological growth forms of gambel oak within the forest/woodland vegetation association can describe 1) the degree of succession of the vegetation type, 2) the quantity of the wildlife habitats within the vegetation type relative to the successional stage, and, 3) the quality of the vegetation type relative to habitat diversity. Assessing important successional growth forms of gambel oak will not only enhance wildlife habitat assessment but can improve ecological management.

INTRODUCTION

Gambel oak (*Quercus gambelii* Nutt.) is an important shrub or tree in mixed conifer, ponderosa pine (*Pinus ponderosa* Laws.), and pinyon-juniper associations in Arizona. Its life forms include brushy thickets, clones of pole size stands, and large individual trees. These life forms are distributed through the forest and woodland stands, providing unique diversity within a rather monotonous conifer overstory. Except for isolated stands of aspen (*Populus tremuloides*), gambel oak is the only deciduous overstory tree in these forest plant communities. An assessment of the interrelationships between conifer and deciduous trees enhances our understanding of conifer forests and woodlands. An evaluation of the successional life forms of gambel oak contributes to knowledge of its role within the forest or woodland type.

Few comprehensive studies have been made on gambel oak as wildlife habitat in Arizona; however, several papers and documents have been written that address specific studies (e.g., Reynolds, Clary, and Ffolliott 1970; McCulloch, Wallmo, and Ffolliott 1965; Goodrum, Reid, and Boyd 1971; Szaro and Balda 1979; Balda 1969). These studies generally included specific uses of oak for wildlife (Patton and Ffolliott 1975), methods of control (Johnsen, Clary, and Ffolliott 1969; Bartel and Rittenhouse 1979; Kufeld 1977; Jefferies 1965), or its role within various forest and woodland habitat types (Layser and Schubert 1979; Moir and Ludwig 1979).

The variety of growth forms of the species provide diversity within habitats; hence, a comprehensive study of these growth forms relative to wildlife habitat is important. Oak growth forms data could easily be incorporated into forest inventories providing a means to quantify diversity of wildlife habitats.

Gambel oak provides the major deciduous overstory diversity within the ponderosa pine forest. Four growth forms occur which provide discreet and distinctive units along a successional gradient. Each form possesses unique ecological characteristics and each has distinct roles as wildlife habitat in the forest ecosystem. Describing successional stages of gambel oak along a gradient could thus relate the impact of disturbance to seral stages. This would provide the manager with an assessment of the forest/woodland condition while also providing a basis upon which to determine the effect of disturbance on wildlife habitat.

A Proposed Method to Quantify Wildlife Habitats

The study objective was to develop a procedure to measure the amount of oak growth forms. The procedure developed must yield measurements of oak growth form composition in units that could be related to habitats of individual wildlife species. The parameters must be able to be easily inserted into present forest survey procedures. It must require little extra effort for the timber cruiser or the compartment examiner, yet be meaningful for the wildlife biologist.

The procedure presented here was tested on three experimental watersheds which had previously been treated for multiple resource management objectives. The sampling units were one square chain (66 ft. X 66 ft.) plots distributed evenly along transects which traversed the watershed. This method of locating sampling units or plots is similar to many other forest inventory procedures. On each sampling unit, oak presence and growth form were recorded. Individual oak trees were classified as post-mature or mature, and numbers recorded. The number of square feet of the brush and/or clone growth form was recorded for each group larger than 25 square feet. With this data the biologist could then determine the amount of brushy or clonal habitat as well as how many post-mature and mature trees there were on the sampled area.

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[1] *Presented as a poster paper at the Ecology and Management of Oak and Associated Woodlands: Perspectives in the Southwestern United States and Northern Mexico. A symposium, Sierra Vista, AZ, April 27-30, 1992.*

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GAMBEL OAK GROWTH FORMS

The Brushy Growth Form

For the purposes of this study a brushy growth form "unit" was identified as an area of sprouts not less than 25 square feet and having stems less than 15 feet tall (fig. 1).

Gambel oak reproduces most commonly by means of suckers (sprouts growing from surface roots) and stool shoots (sprouts growing from the base of the trunk near the root collar) (Brown 1958). Reproduction by seed is less evident than vegetative reproduction (Marquiss 1972; Jefferies 1965). Brown (1958) suggests fire may be the most common stimulus of suckering in oak stands. Since fire is important for the viability of some forest types, specifically ponderosa pine (Cooper 1960), vegetative reproduction of oak is important to maintain this specific growth form.

Neff (1974) found the percent composition of the diet of tame deer to be 25.4% and 46.3% oak foliage for winter and summer feeding trials, respectively. He also suggested that large areas of brush and sprouts resulting from a total overstory removal were important as fawning grounds for deer. Ffolliott (1976) found cottontail rabbit pellet densities were higher on areas with high densities of oak sprouts. Studies on Beaver Creek (Goodwin and Hungerford 1979) showed greater species diversity of rodent populations on areas where oak sprouting was enhanced than on areas where sprouting was controlled. Evidently, brushy growth forms of early successional oak provide improved cover and food for deer, rabbits, and rodents.

Young Pole Stands

Young pole stands or clones of gambel oak are, successionally, an older stage of the brushy growth form (fig .2). This seral stage includes many of the attributes of the brushy form and provides many similar habitat features. The important differences are stem dbh (larger than 3 inches) and height (greater than 15 feet). The value of pole or sapling growth forms as wildlife habitat is more poorly understood than the other three growth forms. Szaro and Balda (1979), however, found use of oak saplings by foliage nesting birds. The taller saplings provide better cover requirements for larger animals and retain the horizontal hiding cover of the brushy forms. The importance of this growth form as specific wildlife habitat needs to be explored further.

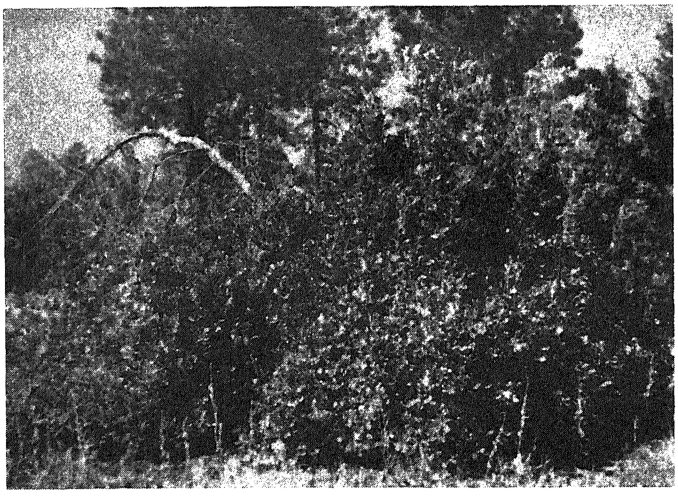

Figure 1. Brushy Growth Form.

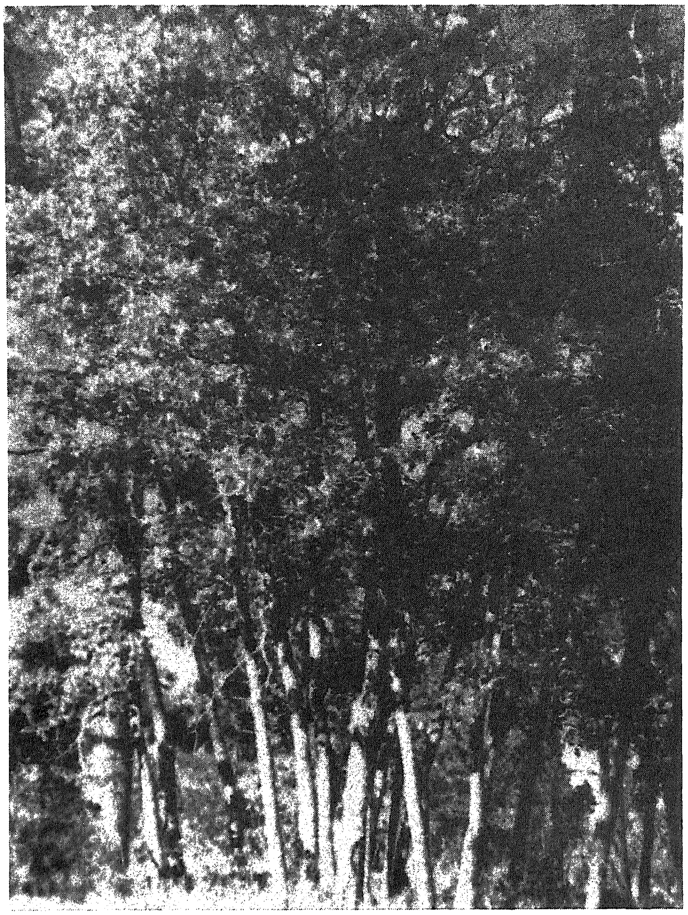

Figure 2. Young Pole Stands.

Post-mature and Mature Growth Forms

Post-mature and mature growth forms are differentiated by vigor classes as described by McCulloch et al. (1965) and Reynolds et al. (1970). Both are large tree forms. Trees in the post-mature growth form contain a large percentage dead crown, show evidence of a hollow bole or limbs, and have low acorn production (fig. 3). This overly mature growth form represents a decadent, less healthy growth form than the mature growth form. The mature growth form is the maximum vigor growth form class, providing maximum acorn yields, having a full live canopy, and may or may not be hollow (fig. 4).

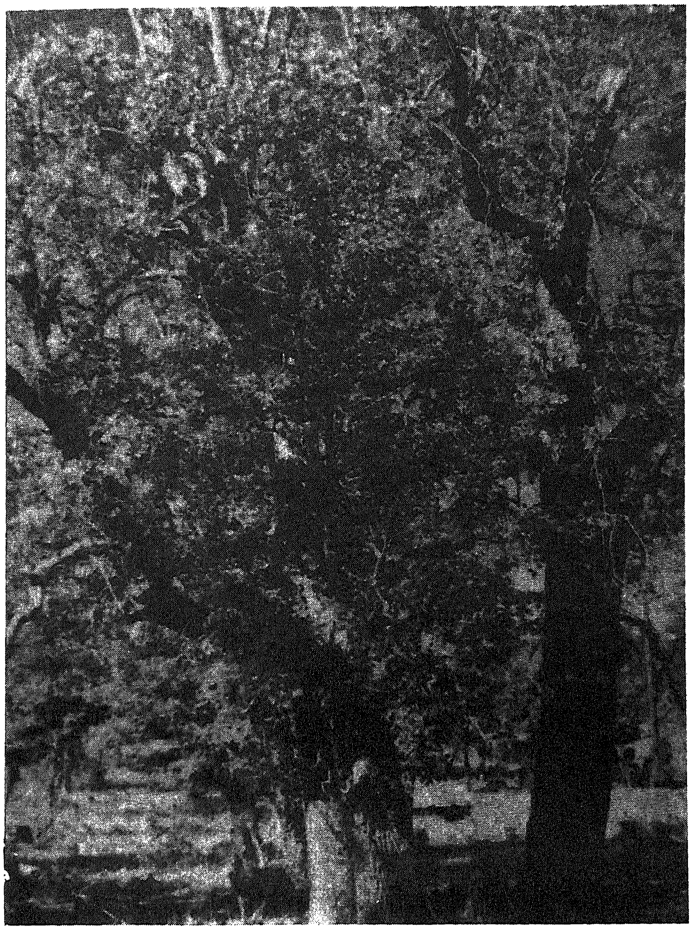

Figure 3. Post-mature Growth Form.

Heart rot caused by *Polyporus dryophilus* is common in gambel oak in central Arizona. In advanced stages, the bole of the tree and the limbs become hollow, yet the tree continues to live. These hollow portions provide unique hiding, resting, and nesting habitat for a variety of small mammals and birds. For some fauna this habitat may be critical; for others, it merely increases habitat diversity. Hollow limbs and boles are used by squirrels, woodrats, bats, and birds, but use as a critical habitat requirement for specific wildlife species is less known.

The importance of mast in the diets of many wildlife species has been documented. Fawn production and survival are related to acorn production (Inlay 1971). Patton (1975) suggests as much as 40 percent of the fall diet of Abert squirrels (*Sciurus aberti* Woodhouse) consists of acorns when a good crop is available. Reynolds et al. (1970) report acorns as preferred food for Abert squirrel, band-tailed pigeons (*Columba faciata* Say), Merriam's turkey (*Meleagris gallopavo* Linnaeus), harlequin quail (*Cyrtonyx montezume* [Vigors]), deer (*Odocoileus* spp.), and elk (*Cervus canadensis* [Erxleben]) in central Arizona.

Post-mature and mature oak growth forms are most sought by fuelwood cutters, creating a serious conflict in some areas. Gambel oak is highly valued fuelwood, and sells on the market for $30-$35 per cord more than other fuelwoods. Pole stands and single tree growth forms are the most efficient to cut. Often, hollow bole oaks are cut accidentally and left in the field. Thus, not only is fuelwood wasted, but wildlife habitat is lost as well. The cutting of high fuelwood volume trees (those that are not hollow) reduces mast production.

Management of gambel oak in Arizona forests must anticipate future demands. Old growth gambel oak does not regenerate quickly and in fact could be lost completely. The species sprouts profusely, however, and management for this growth form as a fuelwood resource requires further investigation. Value of the species as a fuelwood must be weighed against its importance as critical wildlife habitat.

MANAGEMENT IMPLICATIONS

Relating the growth form data to habitat features and ultimately to species is the final step. This requires use of the literature and existing wildlife habitat models. We hope to evaluate these relationships in the field on selected species.

Much of the obvious information about species' habitat requirements (i.e. cavities for cavity nesters, browse for browsing ungulates, etc.) is available. Here we will emphasize critical habitat requirements for threatened, endangered, and sensitive species. We will estimate the elements needed for higher-quality

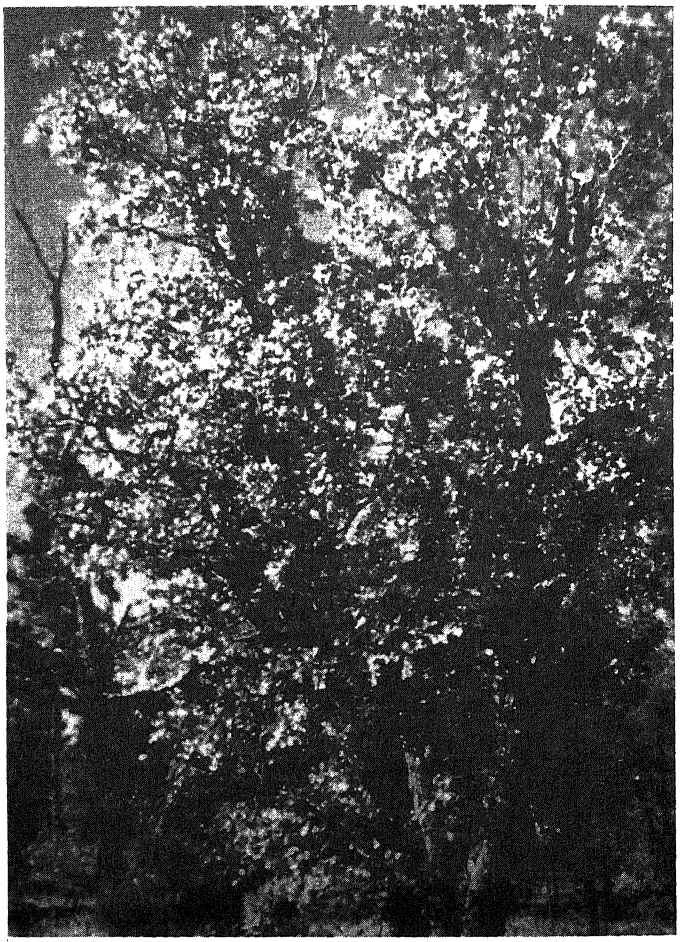

Figure 4. Mature Growth Form.

habitat. We hope to evaluate the relation between habitat preference and population carrying capacity (Hobbs and Hanley 1990).

Improved forest surveys and inventories strengthen management for wildlife habitat. Considerations in management plans should include the following:

- Harvest/treatment procedures should manage oak on a site-to-site basis. Disturbance of oak in any growth form on poorer sites enhances brushy growth forms. Better sites where mature oak forms exist should be considered for protection.
- Present harvest/treatment procedures are probably adequate for stimulating oak sprouting in small patches. Should large brushy areas be desirable (e.g., fawning habitat or browse improvement), fire may be useful. Again, disturbance is suggested for the lower quality sites.
- Heavy thinning of ponderosa pine around post-mature and mature oak growth forms produces the greatest change in the forest habitat close to those oak trees. Consideration should be given to those wildlife species that utilize the oak in some form but also require the conifer overstory as well. Also the disturbance to the conifer overstory may detrimentally affect the well being of the oak growth form.
- Patch cutting (openings less than 10 acres), where shelter-wood cutting of the surrounding pine forest is included, provides the greatest diversity of all oak growth forms and may be the most important management option when specific site factors are included in harvest or treatment planning.
- When oak are to be harvested, oaks that have diameters less than 8 inches or above 15 inches should be selected (Johnsen et al. 1969; Reynolds et al. 1970). All oaks between 8-15 inches dbh should be retained. Oaks outside this range should be evaluated for wildlife activity and trees providing critical habitat, regardless of size, should be retained.
- Treatment plans should prescribe desired results in the amount and diversity of oak forms. If the area to be harvested/treated is lacking in oak sprouts, the prescription should be written to enhance this specific component.

CONCLUSIONS

The management implications could provide the biologist with a quantitative assessment of wildlife habitat diversity within a forest area. However, some other areas where more intensive investigations and considerations should be given are:

- Specific site requirements for each oak growth form.
- Site, climatic, treatment, and biological factors that affect the mature and post-mature growth forms.
- Determining the impacts of fuelwood cutters on the various growth forms.
- Determining specific interactions between wildlife species and the 4 growth forms.

LITERATURE CITED

Balda, Russell P. 1969. Foliage use by birds of the oak-juniper woodland and ponderosa pine forest in southeastern Arizona. The Condor Vol. 71, No. 4, p 399-412.

Bartel, Lawrence E. and Larry R. Rittenhouse. 1979. Herbicidal control of gambel oak root sprouts in southwestern Colorado. Down to Earth. Vol. 36 No.1, p6-9.

Brown, Harry E. 1958. Gambel oak in west-central Colorado. Ecology 39:317-327.

Cooper, Charles F. 1960. Changes in vegetation, structure, and management of southwestern pine forests since white settlement. Ecol. Mono. Vol. 30 No. 2. p.129-164.

Ffolliott, Peter F. 1976. An assessment of Abert squirrel and cottontail activities on Beaver Creek watersheds. Final Report 27 p. SRNR, U of A, Tucson, Ariz.

Goodrum P.D., V.H. Reid, and C.E. Boyd. 1971. Acorn yields, characteristics, and management criteria of oaks for wildlife. J. Wildlife Manage. 35(3):520-532.

Goodwin, John G., Jr., and C. Roger Hungerford. 1979. Rodent population densities and food habits in Arizona ponderosa pine forests. USDA For. Serv. Res. Pap. RM-214, 12 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Hobbs, N. Thompson and Thomas A. Hanley. 1990. Habitat evaluation: Do use/availability data reflect carrying capacity? J. Wildl. Manage. 54(4):515-522.

Inlay. 1971. In: Wildlife-oak tree management coordination guidelines. Ashcraft, Schneegas, and Graves (eds.) Mimeo. California Game and Fish Rep., July 1971.

Jefferies, N. W. 1965. Herbicide studies on gambel's oak in southwestern Colorado. West. Weed Control Conf. Res. Prog. Rep., p. 39-40.

Johnsen, Thomas N., Jr., Warren P. Clary, and Peter F. Ffolliott. 1969. Gambel oak control on the Beaver Creek Pilot watershed in Arizona. USDA Agric. Res. Serv. Pub. ARS 34-104. 7 p. Kufeld, Roland C. 1977. Improving gambel oak ranges for elk and mule deer by spraying with 2,4,5-TP. J. Range Manage. 30(1):53-57.

Layser, Eaele F., and Gilbert H. Schubert. 1979. Preliminary classification for the coniferous forest and woodland series of Arizona and New Mexico. USDA For. Serv. Res. Pap. RM-208, 27 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Marquiss, Robert W. 1972. Soil moisture, forage, and beef production benefits from gambel oak in southwestern Colorado. J. Range Manage. 25(2):146-150.

McCulloch, C. Y., O. C. Wallmo, and Peter F. Ffolliott. 1965. Acorn yield of gambel oak in northern Arizona. USDA For. Serv. Res. Note RM-48, 2 p. Rocky Mtn. For. and Range Exp. Stn., Fort Collins, Colo.

Moir, William H. and John A. Ludwig. 1979. A classification of spruce-fir and mixed conifer habitat types of Arizona and New Mexico. USDA For Serv. Res. Pap. RM-207, 47p. Rocky Mt. For. and Range Exp. Stn. Fort Collins, Colo.

Neff, Don J. 1974. Forage preferences of trained mule deer on the Beaver Creek watersheds. Spec. Rep. No. 4, Arizona Game and Fish Dep., Phoenix, Ariz.

Patton, David R. 1975. Abert squirrel cover requirements in southwestern ponderosa pine. USDA For. Serv. Res. Pap. RM-145, 12 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Patton, David R. and Peter F. Ffolliott. 1975. Selected bibliography of wildlife habitats for the Southwest. USDA For. Serv. Gen. Tech. Pap. RM-16, 39p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, CO 80526.

Reynolds, H. G., Warren P. Clary, and P. F. Ffolliott. 1970. Gambel oak for southwestern wildlife. J. For. 68:545-547.

Szaro, Robert C., and Russell P. Balda. 1979. Effects of harvesting ponderosa pine on nongame bird populations. USDA For. Serv. Res. Pap. RM-212, 8 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Pinyon Ips Outbreak in Pinyon Juniper Woodlands in Northern Arizona: A Case Study[1]

Jill L. Wilson and Borys M. Tkacz[2]

Abstract:–A recent pinyon ips outbreak in pinyon-juniper woodlands was likely initiated by a short, intense drought. Once the outbreak began, the percent mortality was greatest in areas where basal areas were between 100 and 200 sq. ft. per acre. Pinyon dwarf mistletoe was also found at low levels. The percent of infected trees was somewhat greater in the areas where mortality was greater. Pinyon ips attacked trees as small as 2 inches in diameter root collar (DRC) and as large as 11 inches DRC, but seemed to prefer trees between 7 and 11 inches DRC. High risk stands are those with basal areas between 100 and 200 sq ft and many trees with DRC's between 7 and 11 inches.

INTRODUCTION

During 1990 and 1991, pinyon pine, *Pinus edulis* Engelm., mortality was reported in many areas across the woodland type in northern Arizona. One of the largest areas detected was located between Heber and the Chevelon Work Station on the Apache-Sitgreaves National Forests, covering approximately 23,800 acres (Rogers and Conklin, 1991). The primary causal agent was a bark beetle (Coleoptera: Scolytidae), *Ips confusus* (Leconte), however severe drought combined with several other factors including dense stand conditions, and presence of pinyon dwarf mistletoe, *Arceuthobium divaricatum* Engelmann, were thought to have predisposed these areas to attack. This paper will review published information on the biology of the insect and the mistletoe, summarize findings of a survey completed during the summer of 1991, and discuss implications for management of pinyon-juniper woodlands.

I. confusus, the pinyon ips, occurs throughout the southwestern U.S. on *P. edulis* and *P. monophylla* and occasionally other pines (Furniss and Carolin, 1977). It is a small cylindrically shaped brown beetle, characterized by presence of distinctive spines on the posterior edge of the wing covers. At times this insect causes extensive mortality of pinyons. Outbreaks can develop rapidly following operations that injure or uproot trees, as in land clearing operations. Three to four generations are produced annually. Beetles attack trees in large numbers, producing characteristic galleries in the inner bark.

Attack process is mediated by production of airborne chemicals called pheromones. Beetles carry a fungus on their bodies which once innoculated into the tree during attack, grows in the trees' xylem and phloem, and assists the beetles in overcoming the trees' defensive mechanisms.

Pinyon dwarf mistletoe is a parasitic higher plant found only on pinyon pines. It is common on *P. edulis* and *P. monophylla* in the southwestern U.S. The dioecious plants consist of aerial shoots and a rootlike endophytic system embedded within the host. Effects of the parasite on host pinyons include formation of swellings, witches brooms, and presumably reduced radial and height growth. Witches brooms on pinyon are less noticeable than those associated with other dwarf mistletoes (Hawksworth, and Wiens 1972)

SITE DESCRIPTION

Elevations within the study area range from approximately 6300 to 6800 feet. For the two nearest recording stations at Heber and Chevelon Work Station, mean annual precipitation averages 18.7 and 18.5 inches respectively. The most common tree species in the area in order of abundance are pinyon (*P. edulis*), one-seed juniper (*Juniperus monosperma*) and alligator juniper (*J. deppeana*).

METHODS

During late September and early October, 1990 the area was stratified into areas of heavy (H), moderate (M), and light (L) mortality using ocular estimates during aerial detection survey. Based on this stratification one area from each classification was selected for ground survey. Ground surveys were conducted during July, 1991. Within each area, plot clusters were located systematically at half mile intervals along driveable roads. Each plot cluster was located five or ten chains from the road, and consisted of a set of three 1/20th acre plots. On the first plot, species (pinyon or juniper), diameter root collar

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[1] *Poster paper presented at the Symposium on Ecology and Management of Oak and Associated Woodlands: Perspectives in the Southwestern United States and Northern Mexico. Sierra Vista, AZ. April 27-30, 1992.*

[2] *Entomologist and Zone Leader, USDA Forest Service, Southwestern Region, Flagstaff, AZ.*

(DRC), height, tree status (healthy, dead, infested, snag), and cause of death or infestation were recorded for all trees. On the other two plots, located 3 chains on either side of the first, species, size class (less than 3 inches and 3 inches and greater), tree status and causal agent were recorded. In addition, precipitation records were obtained from Chevelon Work Station (10 miles) and the Heber Ranger Station (14 miles).

RESULTS

Ips attacked and killed pinyon as small as 2 inches DRC. The largest diameter attacked was 11 inches, though pinyons ranged up to 21 inches DRC on the plots. In areas H and L the beetles attacked 50 - 100 percent of the trees between 7 and 11 inches DRC and generally less than 50 percent of the trees in the lower diameter classes.

Ground survey results for each area are displayed in Tables 1 and 2. As expected the number of dead and infested trees per acre was greatest in Area H. Mortality levels were almost as high in Area L, which had been classified as receiving only light mortality during the aerial detection survey. The lowest number of attacked trees occurred in Area M. This was unexpected however it is possible that additional mortality occurred in Area L following completion of the aerial detection survey.

Table 1. Trees per acre by area, species, condition, and cause for all plots[1]

Area	Spp	Healthy	Infested			Dead			Stand
			Total	Ips	DM	Total	Ips	DM	Total
H	Pinyon	287.9	13.4	1.2	11.1	110.4	91.2	33.3	411.7
	Juniper	270.7	0.0			13.7			284.4
	Total	558.6	13.4	1.2	11.1	124.1	91.2	33.3	696.1
M	Pinyon	211.9	7.8	1.0	6.8	24.7	7.8	1.0	244.4
	Juniper	223.9	0.0			1.0			224.9
	Total	435.8	7.8	1.0	6.8	25.7	7.8	1.0	469.3
L	Pinyon	218.4	21.1	1.3	21.1	43.1	36.6	3.9	282.6
	Juniper	261.6	0.0			0.0			261.6
	Total	480.0	21.1	1.3	21.1	43.1	36.6	3.9	544.2

[1] Totals include trees infested and killed by Ips, DM, other agents, unknowns and combinations.

Table 2. Basal area per acre by area, species, condition and cause for diameter plots only[2]

Area	Spp	Healthy	Infested			Dead			Stand
			Total	Ips	DM	Total	Ips	DM	Total
H	Pinyon	16.8	2.7	0.5	2.6	25.7	24.7	9.7	45.2
	Juniper	137.2	0.0			3.3			140.5
	Total	154.0	2.7	0.5	2.6	29.0	24.7	9.7	185.7
M	Pinyon	39.0	0.5	0.4	0.0	2.7	1.9	0.0	42.2
	Juniper	71.6	0.0			0.0			71.6
	Total	110.6	0.5			2.7			113.8
L	Pinyon	25.0	0.7	0.0	0.7	21.7	21.5	0.3	47.4
	Juniper	145.4	0.0			0.0			145.4
	Total	170.4	0.7			21.7			192.8

[2] Totals include trees infested or killed by Ips, DM, other agents, unknowns, and combinations.

Pre-outbreak stocking levels were highest in Areas L and H, where mortality levels were greatest, and lowest in M where mortality was lowest. The same trend followed for post-outbreak levels. As expected the greatest percent decrease (17 percent) in stocking occurred in Area H where sq ft of basal area (BA) per acre dropped from 185.7 down to 154. Changes in species composition were also greatest in Area H, where the percentage of pinyon dropped from 61.8 to 53.1, while juniper increased from 38.2 to 46.9.

Plotting the percent mortality by trees per acre (TPA) and BA (both species) for individual plots revealed the distributions shown in figures 1 and 2. The percent of pinyon trees attacked is initially low then rapidly increases at around 400 TPA and 100 BA. The percent trees attacked then gradually decreases as both TPA and BA increase.

Pinyon dwarf mistletoe infection levels were relatively low in the survey area. The percentages of infected trees for areas H, M, and L were 10.8, 3.2, and 8.9 respectively. However, levels in the survey area may have been higher than detected due the difficulty of finding evidence of mistletoe in dead trees except in previously heavily infected ones. Levels of mistletoe infection were highest in areas H and L where numbers of attacked trees were also highest.

Precipitation for 1989 and January through June of 1990 was below average at Chevelon and Heber. In 1989, Chevelon received only 67.9 percent of average precipitation and during January - June it received 73.7 percent. At Heber 86.5 percent of average precipitation fell in 1989 and 76.2 percent during the spring of 1990. The outbreak area was located about halfway in between these two sites.

DISCUSSION

Drought, disease and certain stand conditions (including: high density, average diameter, old age

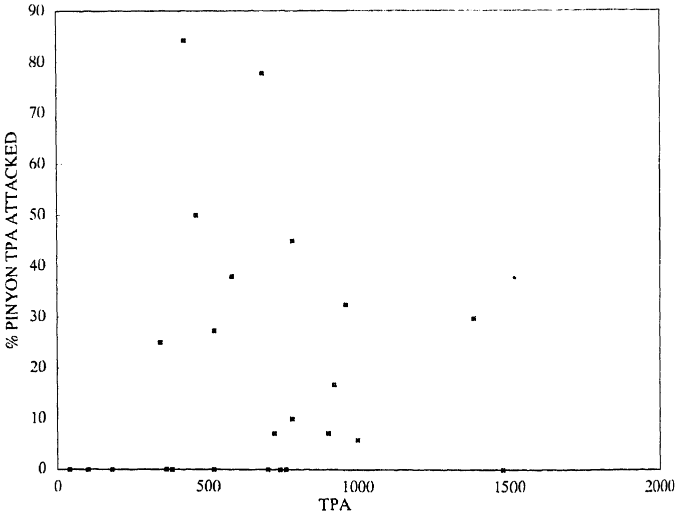

Figure 1. Distribution of the percent of pinyon trees per acre attacked vs trees per acre

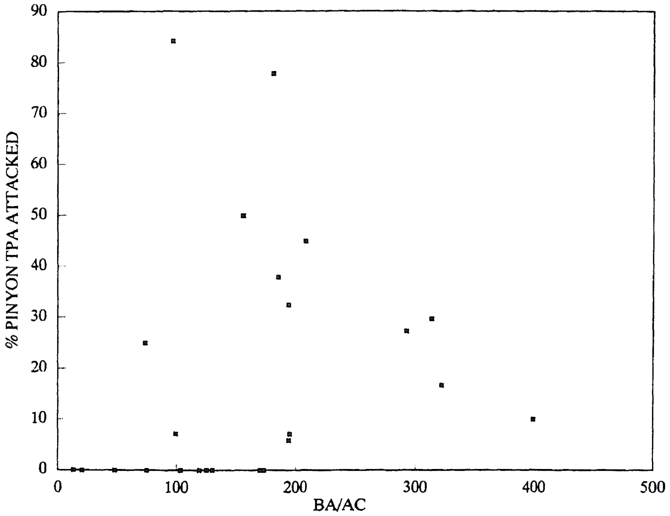

Figure 2. Distribution of the percent of pinyon trees per acre attacked vs sq ft of basal area per acre

etc) have all been implicated as important agents predisposing stands to bark beetle attack. It is thought that these factors induce stress which adversely affect the tree's defensive mechanisms, namely the resin system. In the pinaceae resin is produced in resin ducts that extend both vertically and horizontally in the sapwood and horizontally in the bark (Shrimpton, 1978). Resin flow is initiated when beetles sever the ducts during boring. The resin contains compounds such as the monoterpenes which are toxic to the beetles as well as inhibitory to the growth of fungal associates (Cates and Alexander, 1982). Stress is thought to reduce the production of resin and has been demonstrated in the case of air pollution injury in ponderosa pine (Cobb et al 1968 a and b) and moisture stress (Shrimpton 1978).

Drought has long been implicated as a predisposing agent for engraver beetle outbreaks. In California, spring moisture deficit (April - July) has been correlated with increased risk of significant mortality from *Ips* spp. (Hall, 1956). In particular, Hall reports that when moisture during April - July was 75 percent or less of average the risk was greatest. Moisture stress has been found to increase soluble nitrogenous compounds and sugars in living cells of trees. Both of these materials are important for development of the beetles and their associated fungi (Shrimpton 1978). Thus moisture stress may influence tree susceptibility in two ways, first by reducing the trees ability to resist attack and second by increasing the nutritional quality of the host for the beetles. The drought in the survey area, though short, was quite intense. It seems likely that this event precipitated the occurrence of the recent *Ips* outbreak near Heber and Chevelon.

Presence of dwarf mistletoe has been implicated as an agent predisposing ponderosa pine trees to attack by *Ips* spp. (Parker 1991, Hawksworth and Geils 1990). On several of the plots examined during this study, many of the trees killed during this outbreak were heavily infected with pinyon dwarf mistletoe. In addition, the percentages of infected trees were somewhat greater on the two areas with the greatest mortality levels. However since overall levels of mistletoe appeared to be fairly low in the study areas, it is not clear how much of a role this pathogen played in initiating this outbreak.

High stand densities have been reported to be associated with the greater likelihood of *Ips pini* attack (Sartwell et al, 1971). This paper recommends thinning to reduce the risk of mortality to these insects in ponderosa pine.

Another way to examine the relationship between mortality and density is to plot the distribution of the percent trees attacked vs. density. Anhold et al (1987) did this with mountain pine beetle in lodgepole pine, plotting the percent trees attacked against stand density index (SDI). They found the proportion of trees attacked was quite low initially then increased as SDI increased and then decreased at the highest levels of SDI.

Data from this study suggest that a similar phenomenon may be true for pinyon ips in pinyon-juniper woodlands. The susceptible areas were those with stocking levels between about 100 and 300 BA. The greatest percentages of trees attacked occurred in stands with stocking levels between 100 and 200 BA.

It appears that the timing of this outbreak was related to the severe drought in 1989-90. Once the outbreak began, the effects were greatest in areas where stocking levels were equal to or greater than 100 BA and less than 200 BA. Presence of pinyon dwarf mistletoe may have increased susceptibility of trees in some areas. Only trees between 2 and 11 inches DRC were attacked and the beetles seemed to display a preference for trees between 7 and 11 inches DRC. The results from this study suggest that high risk stands for pinyon ips attack are those with 100 to 200 BA and many trees with DRC's between 7 and 11 inches.

LITERATURE CITED

Anhold, J.A. and M.J. Jenkins. 1987. Potential Mountain Pine Beetle (Coleoptera: Scolytidae) Attack of Lodgepole Pine as described by Stand Density Index. Env. Entomology 16:738-742.

Cates, R.G., and H. Alexander. 1982. Host Resistance and Susceptibility. PP 212-263 In: J.B. Mitton and K.B. Sturgeon (eds.). Bark Beetles in North American Conifers: A System for the Study of Evolutionary Biology. University of Texas Press. Austin.

Cobb, F.W., D.L. Wood, R.W. Stark and P.R. Miller. 1968a. Photochemical oxidant injury and bark beetle (Coleoptera: Scolytidae) infestation of ponderosa pine. II. Effect of injury upon physical properties of oleoresin moisture content and [hloem thickness. Hilgardia 39:127-134.

Cobb, F.W., D.L. Wood, R.W. Stark, and J.R. Parmeter. 1968b. Photochemical oxidant injury and bark beetle (Coleoptera: Scolytidae) infestation of ponderosa pine. IV. Theory on the relationship between oxidant injury and bark beetle infestation. Hilgardia 39: 141-152.

Furniss, R.L. and V.M. Carolin. 1977. Western Forest Insects. USDA Forest Service Miscellaneous Publication No. 1339. 654 pp.

Hall, R.C. 1956. Environmental Factors associated with outbreaks by the western pine beetle and the California five-spined pine engraver in California. Tenth International Congress Ent. Montreal (1956) 4.

Hawksworth, F.G., and B.W. Geils. 1990. How Long do Mistletoe-infected Ponderosa Pines Live? Western J. of Applied Forestry 5:47-48.

Hawksworth, F.G., and D. Wiens. 1972. Biology and Classification of Dwarf Mistletoes (Arceuthobium). USDA Forest Service Agriculture Handbook No. 401. 234 pp.

Parker, D.L. 1991. Integrated Pest Management Guide. Arizona Five-Spined Ips, *Ips lecontei* Swaine, and Pine Engraver, *Ips pini* (Say), in Ponderosa Pine. USDA Forest Service, Forest Pest Management Report R3 91-8, 17 p. Southwestern Region, Albuquerque, NM.

Rogers, T. and D. Conklin. 1990. Annual Southwestern Region Pest Conditions Report. USDA Forest Service, Forest Pest Management Report R3-91-5, 30 p. Southwestern Region, Albuquerque, NM.

Sartwell, C., R.F. Schmitz, and W.J. Buckhorn. 1971. Pine Engraver, *Ips pini,* in the Western States. USDA Forest Service Forest Pest Leaflet 122. 5p.

Shrimpton, D.M. 1978. Resistance of Lodgepole pine to Mountain Pine Beetle Infestation. PP 64-76 In A.A. Berryman, G.D. Amman, R.W. Stark, and D.L. Kibbee (eds.). Theory and Practice of Mountain Pine Beetle Management in Lodgepole Pine Forests - A Symposium. April 25-27. College of Forest Resources. Univ. of Idaho, Moscow.

Factors Controlling Lower Elevational Limits of Plants: Responses of Pines to Drought in the Chiricahua Mountains, Arizona[1]

Andrew M. Barton[2]

Six pine species occur at different elevational positions in the Chiricahua Mountains. In this study, four lines of evidence suggested that drought and relative drought resistance control lower elevational limits of these species: (1) soil moisture decreased from high to low elevation; (2) in a greenhouse drought, lower elevation species survived longer and were better able to maintain CO_2 uptake and water potential than higher species; (3) near lower elevational limits, seedlings of each species occurred in relatively moist microsites; and (4) below their respective lower limits, species germinated but subsequently died, apparently from water stress. Elevational position of a given pine species appears to depend on the relative ability of its young seedlings to maintain water balance during their first several dry seasons.

INTRODUCTION

In semi-arid zones, elevational positions of plants are potentially controlled by many environmental variables correlated with elevation (Shreve 1915, Daubenmire 1943a). Since 1986, I have investigated the role of three variables -- drought, fire, and competition for light -- in the elevational positions of pine species in the Chiricahua Mountains in southeast Arizona (Barton 1991, Barton and Teeri 1992). Here, I report on aspects of that work related to drought. Using greenhouse experiments on relative drought resistance of species, documentation of seedling microsites, and field experiments at different elevational positions, I test the hypothesis that drought and relative drought resistance control lower elevational limits of these species.

STUDY AREA AND SPECIES

The Chiricahua Mountains, located in southeastern Arizona (31° 52' N latitude, 109° 15' W longitude), experience a semi-arid climate, with two wet seasons, one between July and September, when more than 50% of total precipitation falls, and the second between December and March. A pronounced dry season usually occurs between the final winter storms in March or April and the onset of the rainy season in July (Sellers, Hill, and Sanderson-Rae 1985).

Six pine species occur commonly in the Chiricahua Mountains at unique but overlapping elevational positions (fig. 1). At least over the range of the lower four pine species, soil moisture during the dry season decreases from high to low elevation (Barton 1991). For details on the study area and environmental changes over the elevational gradient, see Barton (1991).

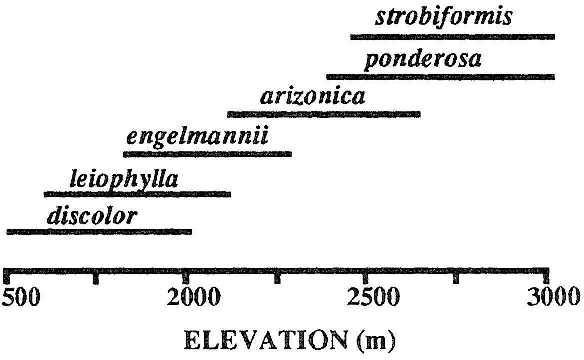

Figure 1. Elevational ranges of the six common pine species along a transect in the Chiricahua Mountains, Arizona.

METHODS AND RESULTS: TESTS OF HYPOTHESES

Greenhouse Experiments

Barton and Teeri (1992) examined the drought hypothesis with five pine species from the Chiricahua Mountains by testing the prediction that relative drought resistance increases from high to low elevation species. Relative drought resistance was assessed by comparing species for both gas exchange and survival responses to a drought imposed in a greenhouse in 1987-1988.

Prior to the drought, three-month old seedlings were drought-hardened for two five-day periods and then divided into two groups. In the first group, seedlings were observed daily through the drought until "death," defined as complete loss of turgor. From the second group, three seedlings of each species were sampled for CO_2 uptake and plant water potential at each of seven dates spread over 29 days of intensifying drought.

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[1] Poster presented at the Symposium on Ecology and Management of Oak and Associated Woodlands, Sierra Vista, Arizona, April 27-30, 1992.

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As expected, lower elevation species survived longer during the drought treatment than did higher elevation species (fig. 2). Seedlings of *P. discolor*, the lowest elevation species, survived longer than did those of the second lowest elevation species, *P. leiophylla*, both of which survived longer than all three species from higher elevations (fig. 2).

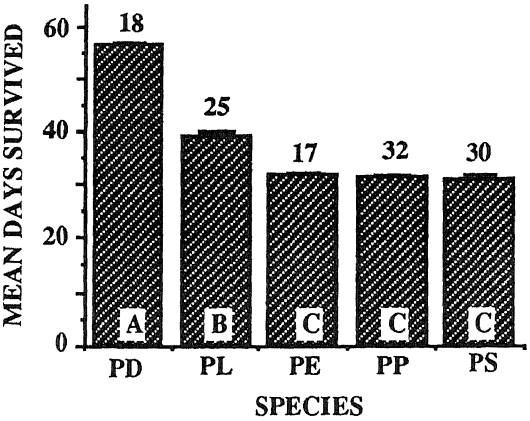

Figure 2. Mean number of days survived from last watering for individuals of each of five pine species. Sample sizes are given at the tops of SE bars. Means that do not share the same letter are significantly different (P<.05, C method). PD=*P. discolor*, PL=*P. leiophylla*, PE=*P. engelmannii*, PP=*P. ponderosa*, PS=*P. strobiformis*. Elevational position of pines increases from left to right.

For all species, net CO_2 uptake and plant water potential decreased as the greenhouse drought intensified ($p<.01$; see fig. 3). For species able to maintain these processes at favorable levels despite increasing drought, the slope of these decreases should be less than for species without such ability. Thus, I based gas exchange analyses on the assumption that lower slopes reflected greater drought resistance.

Carbon dioxide uptake of the three higher elevation species decreased to less than 25% of well-watered controls by the 16th day of drought and dropped to zero by day 29. The lower two species were able to maintain levels above 50% of controls on day 16 and still exhibited positive CO_2 gain on day 29. As expected, the slope of decrease in CO_2 uptake was significantly less for lower than for higher elevation species (F-test, $p<.05$), indicating increasing resistance to drought from higher to lower elevation species.

The main differences among species in the response of plant water potential to the drought appeared on day 29 (fig. 3). Whereas the two lower elevation species experienced no decrease (*P. leiophylla*) or only a moderate decrease (*P. discolor*), the water potential of the three upper elevation species dropped precipitously, in most cases to the minimum detectable by the pressure bomb (-4 MPa). As for CO_2 uptake, the slope in loss of water potential was significantly less for lower than for higher elevation species (F-test, $p<.05$).

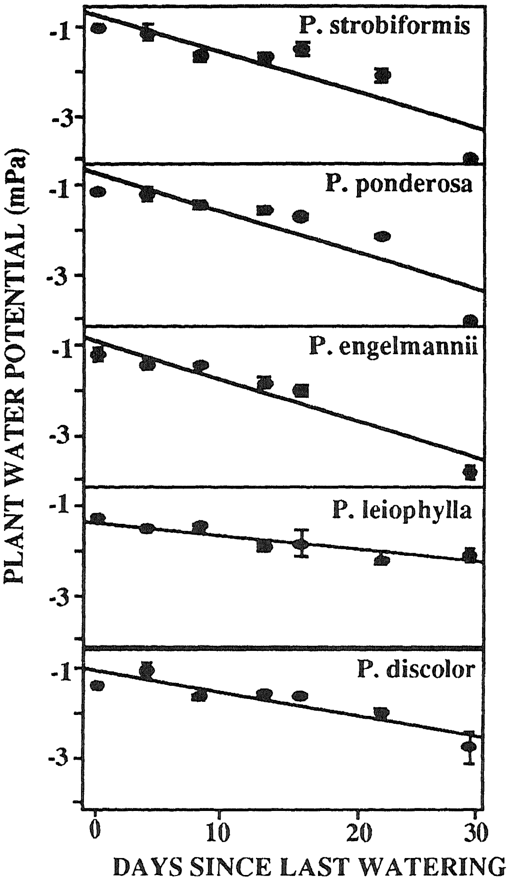

Figure 3. Mean (with SE) plant water potential over 29 days during which water was withheld. Sample size is two for *P. discolor* for day four and three for all others. Elevational position of species increases from lower to upper frames.

Seedling microsites

In the field, I tested the hypothesis that drought controls lower elevational limits of the pines by comparing the microsites occupied by pine seedlings with random microsites. For each of the lower three species (*discolor, leiophylla, and englemannii*), I simultaneously measured the environment of seedling and random microsites at midday in June 1988 in plots (11-23 depending on species) scattered over the elevational gradient.

At each microsite, I measured photosynthetically active light (at 10 cm above the ground), litter depth (to mineral soil), and soil temperature (at 7 cm depth). It was not feasible to measure soil moisture directly at all of these sites. Instead, I used two separate investigations to relate moisture to the three measured variables. First, at lower elevations, soil moisture was significantly higher (at 7 cm depth) under vegetation ("nurse trees") compared to open sites; nurse tree sites had substantially lower light, deeper litter, and lower temperature than open sites (Barton 1991). Second, within plots at all elevations, soil moisture available to plants increased with increasing litter depth and decreasing light availability (Barton 1991). Thus, overall, soil moisture was consistently higher in more mesic or protected microsites than in neighboring open microsites.

If drought controls the lower elevational limits of species, then from high to low elevation plots, plants should increasingly occupy microsites with low soil temperature, low light, and deep litter compared to random microsites. The results strongly support this prediction for the lower two species. Seedlings of *P. discolor* occurred in microsites similar to random at higher elevation, but were found in extremely mesic conditions relative to random microsites near its lower elevational limit (light: F=24.13, p<.001; soil temperature: F=126.41, p<.001; litter: F=8.12, p<.01); most of these sites were conspicuous "nurse tree" microsites, under either *Quercus* spp. or *Juniperus deppeana*. *P. leiophylla* exhibited a similar, although much less extreme, pattern (light: F=10.91, p<.01; soil temperature: F=51.01, p<.001; litter: F=8.65, p<.01). *P. engelmannii* seedlings occurred in microsites with significantly less light than random (F=4.84, p<.05), but results for soil temperature and litter were insignificant (F-tests, p>.10).

Field Experiments

For each of the lower three species, I tested whether lack of germination below current lower elevational limits of each species was responsible for these limits. To assess whether first-year seedling mortality was important in enforcing lower limits, I followed the survival of seedlings resulting from these seedings and from similar seedings within the normal range of each species.

Seeds of each species were planted in small experimental plots at the beginning of the 1987 rainy season just below their respective lower elevational limit (low) and near their elevational mode for adult abundance (middle). Germinants were tallied twice per week and survival followed weekly for two months and then periodically for two years.

Seeds of each species germinated below their lower elevational limits, although in reduced numbers compared to the middle elevational positions (Mann-Whitney U-tests, p<.05). However, all seedlings at low elevational positions died by the end of the first May-June dry season (fig. 4). Although some deaths were attributable to herbivory, most seedlings exhibited typical symptoms of water stress (Levitt 1980). In contrast, many seedlings of each species were still alive after one year at middle elevational positions (fig. 4).

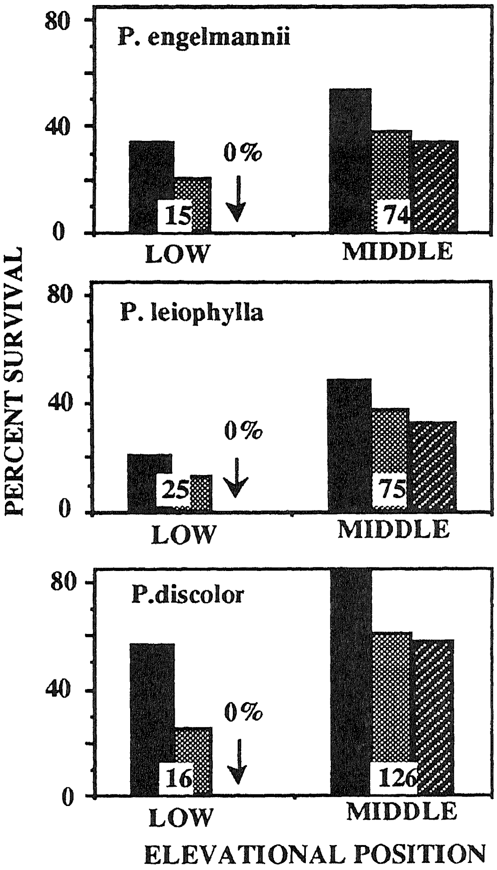

Figure 4. Seedling survival at low (below each species' respective lower elevational limit) and at middle elevational positions (near mode for abundance) from experimental plantings. From left to right, bars represent survival after 2 months (solid), 9 months (stippled), and 12 months (cross-hatched). Number of seedlings is shown at bottom of bars. Differences between low and middle positions are significant for each species at each date (G-test, p<.05).

CONCLUSIONS

Pine species in the Chiricahua Mountains occur at distinctly different elevational positions. Four results of this study suggest that drought and drought resistance are crucial in controlling these distributions in the Chiricahua Mountains: (1) soil moisture decreased from high to low elevation, (2) lower elevation species were more drought resistance than higher elevation species, (3) seedlings appeared to occur increasingly in moist microsites from high elevation to their lower elevational limits, and (4) although seeds germinated below each species' lower limit, all seedlings died by the end of the first severe dry season apparently from water stress.

Other experimental studies have also concluded that water stress and drought resistance control lower elevational limits of trees in western USA mountains (Pearson 1931, Daubenmire 1943b, Wright 1968, 1970, Bunce, Chabot, and Miller 1979, Barnes and Cunningham 1987). However, few studies in desert mountains have tested alternative variables that also correlate with elevational gradients: tolerance of high temperature (Wright 1968), fire (Barton 1991), deep litter under nurse trees (Barton 1991), and competition (Daubenmire 1943a, Yeaton 1981).

Each species was able to germinate at sites below its lower elevational limit, but survival there was very poor. Similarly, survival of natural first-year seedlings was low for each species near its lower boundary (Barton 1991). In contrast, seedling growth rates for each species increased substantially from high to low elevations (Barton 1991). Thus, dry season water stress appears to control lower elevational limits by causing high mortality of young seedlings, rather than by curtailing germination or performance of older seedlings.

Differences among pines in drought resistance at this vulnerable stage, thus, appear crucial in determining elevational positions. These differences may depend on ability to maintain favorable carbon balance (see Bunce et al. 1979): the two lowest elevation species were better able to maintain CO_2 uptake during the drought experiment. In the three upper elevation species, however, there was a striking correspondence in time between a precipitous water potential loss (days 22-29) and mortality (mean of about 31 days). The two lower elevation species did not experience this water potential drop and survived for much longer. Differences among the species in survival, therefore, apparently resulted more from abilities in maintaining water balance than in maintaining carbon balance.

Just above each species' lower limits, successful establishment appears to occur primarily under nurse trees, where moisture is ameliorated. Probably because of its large seeds, *P. discolor* is much more effective at this strategy than the other two species, occurring in extremely moderated conditions relative to random microsites and microsites in which the other two species occur. Once established with a deep root system, these seedlings are probably much less vulnerable to the effects of water stress and, as a result, grow well in the relatively warm, long growing seasons characteristic of lower elevations.

LITERATURE CITED

Barnes, F. J. and G. L. Cunningham. 1987. Water relations and productivity in pinyon-juniper habitat types. Pages 406-411 *in* R. L. Everett, editors. Proceedings - Pinyon-juniper conference. USDA Forest Service, General Technical Report INT-215.

Barton, A.M. 1991. Factors controlling the elevational positions of pines in the Chiricahua Mountains, AZ: drought, competition, and fire. Ph. D. dissertation, University of Michigan, Ann Arbor, MI, USA.

Barton, A.M and J.A. Teeri. 1992. The ecology of elevational positions in plants: drought resistance in five montane pine species in southeast Arizona. American Journal of Botany, in press.

Bunce, J. A., B. F. Chabot, and L. N. Miller. 1979. Role of annual leaf carbon balance in the distribution of plant species along an elevational gradient. Botanical Gazette 140: 288-294.

Daubenmire, R. F. 1943a. Vegetation zonation in the Rocky Mountains. Botanical Review 9: 325-393.

Daubenmire, R. F. 1943b. Soil temperature versus drouth as a factor determining lower altitudinal limits of trees in the Rocky Mountains. Botanical Gazette 105: 1-13.

Levitt, J. 1980. Responses of plants to environmental stresses. Volume II. Water, radiation, salt, and other stresses. Academic Press, New York, USA.

Pearson, G. A. 1931. Forest types in the southwest as determined by climate and soil. United States Department of Agriculture Technical Bulletin 247: 1-144.

Sellers, W. D., R. H. Hill, and M. Sanderson-Rae. 1985. Arizona climate. University of Arizona Press, Tucson, AZ.

Shreve, F. 1915. The vegetation of a desert mountain range as conditioned by climatic factors. Publication No. 217, Carnegie Institution of Washington, Washington, District of Columbia, USA.

Wright, R. D. 1968. Lower elevational limits of montane trees. II. Environment-keyed responses of three conifer species. Botanical Gazette 129: 219-226.

Wright, R. D. 1970. CO_2 exchange of seedling pines in the laboratory as related to lower elevational limits. American Midland Naturalist 83: 291-300.

Yeaton, R. I. 1981. Seedling characteristics and elevational distributions of pines (Pinaceae) in the Sierra Nevada of central California: a hypothesis. Madrono 28: 67-77.

Inonotus andersonii: A Wood Decay Fungus of Oak Trees in Arizona[1]

M. L. Fairweather and Robert L. Gilbertson[2]

Abstract.–*Inonotus andersonii* decays trees in oak woodland areas throughout the state of Arizona. In vitro decay and vegetative incompatibility relationships between isolates of *I. andersonii* were investigated. There were no significant differences ($P=0.05$) in the rates of decay of the different species of oaks tested (*Quercus emoryi*, *Q. arizonica*, *Q. gambelii*, and *Q. hypoleucoides*). However, sycamore, alder, and spruce were decayed at a significantly slower rate. Distinct zones of interaction developed between all isolates paired on MEA. Pigmented interaction zones were also observed in wood naturally infected and decayed by *I. andersonii*. Individual infected trees may have a population of different genotypes of *I. andersonii* exhibiting vegetative incompatibility. Field observations in Arizona indicate all species of oak are susceptible to decay by *I. andersonii*. Advanced decay and mortality occurs in older trees. Decayed branches often break off leaving a live tree with hollowed cavities which provide habitat for cavity nesting birds and other wildlife species. *Inonotus andersonii* is considered beneficial to oak woodland ecosystems. Isolations were unsuccessful from a tree if fruiting (basidiocarp formation) had occurred more than one or two years previously. Apparently other micro-organisms quickly colonize decayed, exposed wood.

INTRODUCTION

Inonotus andersonii (Ell. and Everh.) Cerny (Aphyllophorales: Hymenochaetaceae) is a major cause of oak tree decay and mortality. This fungus enters trees through wounds or branch stubs. After decaying heartwood it moves into the sapwood. Unlike many wood decay fungi held in check by host defenses, *I. andersonii* ultimately girdles the cambial region, killing the tree. The resupinate rusty-orange sporophore develops under the bark or outer layers of sapwood of recently killed standing or fallen trees, rupturing the host tissue to expose irregular spore bearing tubes. The fruiting structure blackens quickly and gives the appearance of a fire scar (Fig. 1). Although *I. andersonii* has been reported on willow, poplar and hickory, it is most commonly found on species of oak (*Quercus*).

Inonotus andersonii has been reported from North America, China, U.S.S.R., and Czechoslovakia (Domanski 1972). In the U.S. it is found throughout hardwood areas of the Midwest, Southeast, and Southwest to California and north to Oregon along the Pacific Coast (Gilbertson and Ryvarden 1986). Studies conducted in southern and midwestern hardwood areas of the U.S. report that *I. andersonii* is the second most common fungus associated with

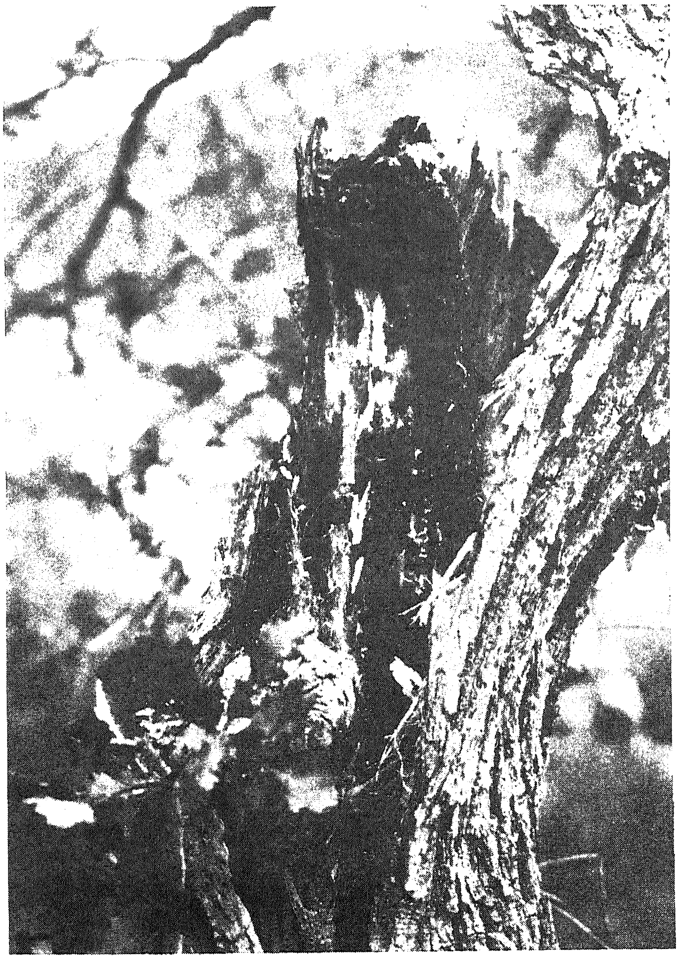

Figure 1. Basidiocarp of *I. andersonii* on Gambel oak.

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[1] *Poster presented at the symposium on Ecology and Management of Oak and Associated Woodlands, April 27-30, 1992, Sierra Vista, AZ.*

[2] *Plant Pathologist, Southwestern Region, USDA Forest Service, Flagstaff; and Professor, Department of Plant Pathology, University of Arizona, Tucson, AZ.*

decay in oak (Berry and Lombard 1978; Toole 1961), causing more trunk rot than any other fungus (Genaux and Kuenzel 1939; Berry and Lombard 1978). The objectives of this study were to examine the decay capacity of vegetative isolates in the wood of host and non-host trees, to investigate vegetative incompatibility between isolates, and to identify the host range and effects of *I. andersonii* in Arizona.

METHODS

Vegetative Incompatibility

Heterokaryotic *I. andersonii* isolates were paired on 2 percent MEA in all possible combinations, with three replications of each pairing. Isolates were placed 5 cm apart on 25 ml of MEA in Petri dishes and incubated at 32 C. Self-crosses served as controls. Hyphal interactions between opposing cultures were noted after 10 weeks. Pairings between isolates were also made on silverleaf oak test blocks to observe and compare interactions on wood. Test blocks were prepared according to the methods of Goldstein and Gilbertson (1981). Pairings were replicated three times. After 20 weeks incubation at 32 C, mycelium was removed and blocks cut in half lengthwise for examination of interaction zones.

Decay Test

The decay capacity of *I. andersonii* was evaluated using three isolates and test blocks prepared from four oak species, two associated hardwoods of Southern Arizona, and a conifer. The wood types used were: *Quercus emoryii* Torr. (emory oak), *Q. arizonica* Sarg. (Arizona white oak), *Q. gambelii* (Gambel oak), *Q. hypoleucoides* A. Camus (silverleaf oak), *Platanus wrightii* S. Wats. (Arizona sycamore), *Fraxinus velutina* Torr. (velvet ash), and *Picea engelmannii* Parry (Engelmann spruce). Wood was cut into 1/2 X 2 X 3 cm blocks. The test blocks were dried in a forced air oven at 110 C for 48 hr, placed in a desiccator for 2 hr, weighed, and autoclaved 1 hr. Decay chambers were made from 8oz. French square bottles containing 25 ml of MEA. The blocks were placed on glass rods and the agar was inoculated with a plug from an actively growing culture of *I. andersonii.* Five replications were prepared for each isolate-wood combination and five chambers of each wood type without the fungus served as controls. The chambers were incubated at 32 C for 28 weeks. The decayed blocks were carefully stripped of the thick masses of hyphae, oven dried at 110 C for 48 hr, desiccated for 2 hr, and weighed. Percentage weight loss based on original oven dry weight served as a relative measure of decay capabilities of tested isolates.

Field Observations

Oak woodlands on the Coronado, Coconino, Kaibab, and Tonto National Forests were observed for oak species infected by *I. andersonii*, severity of infection within an area, and use of infected trees by wildlife. *Inonotus andersonii* forms annual resupinate basidiocarps with very thin context tissue which deteriorates rapidly. Consequently, isolations were attempted from decayed wood rather than from fruiting structures.

RESULTS

Vegetative Incompatibility

All pairings between different heterokaryotic isolates resulted in similar antagonistic interaction zones. The results are shown in Table I. *Inonotus andersonii* isolates characteristically develop thick hyphal mats on 2 percent MEA. When paired, opposing cultures grew within 1-3mm (in rare instances 5-7mm) of one another. The hyphae were sparse in the narrow darkly pigmented zone between the two isolates. The interface margins of each opposing mat were characterized by a dense buildup of darkly pigmented hyphae which were swollen, contorted, and twisted together. In a few instances the entire area occupied by one isolate was darkly pigmented and the hyphae remained submerged. Self-paired isolates were compatible. Results from pairing different heterokaryotic isolates in silverleaf oak blocks were similar. Non-self pairings resulted in regions of undecayed wood where opposing isolates interacted, an area characterized by a zone of darker permanently stained wood. Compatible reactions between self-paired isolates were characterized by the uniform color of decay and the absence of dark interaction zones.

Table I. Interactions of heterokaryotic isolates of *Inonotus andersonii* on 2% MEA.

	RLG 16145	L 4937	FP 72121	FP 89835	FP 94289	CS 659214	MLF 56
RLG 16145	—	+	++	+	+	++	+
L 4937		—	+	+	+	+	+
FP72121			—	+	+	+	+
FP 89835				—	+	+	+
FP 94289					—	+	+
CS 659214						—	+
MLF 56							—

—: no interaction zone; +: interaction zone 1-3mm; ++: interaction zone 5-7mm.

Decay Test

The results from the decay test are shown in Table II. After 28 weeks, the average percent weight loss for each wood type-isolate combination was determined only from growth chambers containing moist wood in which the fungus was still active. Although each wood type was decayed by *I. andersonii*, overall, the oaks were decayed at a significantly faster rate (P=0.05) than the other hardwoods and spruce. The average weight loss of oak wood ranged from 30% to almost 53%. The next most decayed wood type was

Arizona sycamore (13-28% weight loss), followed by spruce (12-17% weight loss), and finally velvet ash (6-7% weight loss). Decay by one isolate (FP 94289) resulted in significantly greater weight loss (P=0.05), overall, on most wood types than the other two isolates used in this experiment.

Table II. Average weight loss of *in vitro* decayed wood by 3 isolates of *Inonotus andersonii* expressed as a percent of original oven-dry weight.*

		Isolate ***			
Substrate	**	L 4937 b	FP 89835 b	FP 94289 a	control
Gambel oak	A	35.73	37.53	52.13	3.43
Emory oak	A	30.47	36.20	48.20	1.30
silverleaf oak	A	39.16	27.96	36.10	3.43
Arizona white oak	A	35.52	38.22	52.88	1.81
Arizona sycamore	B	13.30	23.76	27.78	0.05
velvet ash	C	7.27	5.69	5.73	0.08
Engelmann spruce	C	12.39	14.02	16.50	1.50

*: Average percent weight loss determined after 28 weeks.
**: Wood-types followed by the same letter were not decayed at a significantly different rate at P=0.05, Duncan Analysis.
***: Decay rate was not significantly different among isolates followed by the same letter at P=0.05, Duncan Analysis.

Field Observations

Inonotus andersonii is found in oak woodland areas throughout the state of Arizona. Infected species include *Quercus emoryii* Torr. (emory oak), *Q. arizonica* Sarg. (Arizona white oak), *Q. gambelii* (Gambel oak), *Q. hypoleucoides* A. Camus (silverleaf oak), and *Q. oblongifolia* Torr. (Mexican blue oak). In many cases, the upper part of a tree had rotted and broken off but the tree was still alive (Fig. 1). Some of these trees had woodpecker cavities and other signs of wildlife use.

Sterile isolations were more successful if attempted shortly after fruiting or before basidiocarp formation, and not successful from trees in which the fungus had fruited more than one year previously. Apparently other micro-organisms invade areas colonized by *I. andersonii* once they are exposed to the outside environment.

DISCUSSION

Distinct zones of interaction develop between different heterokaryotic isolates of *I. andersonii* paired on MEA and wood test blocks. The substrate is pigmented and the hyphae adjacent to the interaction zone are knotted and swollen. Similar reactions have been described from intraspecific pairings of other wood decay fungi (Goldstein and Gilbertson 1981; Rayner and Todd 1977; and Childs 1963), and vegetative incompatibility is considered widespread in fungi.

In wood test blocks, the area adjacent to the zone of interaction remains undecayed. Rayner and Todd (1977, 1978) observed similar antagonistic reactions and pigmentation in wood decayed by *Trametes versicolor* (=*Coriolus versicolor* (L:Fr.) Quel.). Adams and Roth (1969) examined the upper boles of damaged Douglas-fir trees and retrieved different genotypes of *Fomitopsis cajanderi* (Karst.) Dotl. et Pouz. separated in the wood by lines of demarcation. Both *F. cajanderi* and *I. andersonii* infect the host through dispersal and germination of basidiospores. In this study, pigmented interaction zones were observed in wood naturally infected and decayed by *I. andersonii.* The fungus exists as a population of different genotypes exhibiting vegetative incompatibility.

Inonotus andersonii could not be isolated from decayed wood if fruiting had occurred more than a year previously. This may indicate *I. andersonii* competes better against other genotypes of itself than it does with other species. However, *I. andersonii* is an early successional stage of decay and once its food source is depleted other organisms may be able to colonize the decayed wood.

All species of oak trees in Arizona are susceptible to infection by *I. andersonii.* In this study, there was no significant difference in the decay rate of different species oak by *I. andersonii.* However, one isolate did decay all oak species at a significantly faster rate than the other two, indicating variability among isolates. The rate of decay was between 30 to 53 percent of dry volume weight after 26 weeks. This is probably faster than would occur in nature since laboratory conditions provided optimum temperature and moisture levels for the fungus.

Although *I. andersonii* is able to girdle and kill the cambium, infected trees are frequently windthrown due to structural loss from advanced decay. Often it is only decayed branches which break off, leaving live trees which provide long term habitat for birds and mammals. *Inonotus andersonii* decays trees slowly and is therefore more common in older trees. This fungus does not infect regeneration. The presence and severity of infection is variable. Where it occurs, the severity of infection is associated with the density of large oak trees. Stem decays have been considered detrimental to forested lands because they decrease wood fiber production. However, fiber production is not the only emphasis of oak management in Arizona. Stem decays like *I. andersonii* are functional members of an ecosystem, which provide wildlife habitat and commence nutrient cycling before trees fall to the ground. *Inonotus andersonii* assists in the sustainability of oak woodland ecosystems because it provides wildlife habitat by creating snags and live trees with snag characteristics. Regeneration potential is not severely impacted because acorn production continues in infected trees while they are still alive.

LITERATURE CITED

Adams, D.H., and L.F. Roth. 1969. Intraspecific competition among genotypes of *Fomes cajanderi* decaying young-growth Douglas-fir. Forest Sci. 15: 327-331.

Berry, F.H., and F.F. Lombard. 1978. Basidiomycetes associated with decay of living oak trees. U.S. Forest Serv. Res. Paper NE-413: 1-8.

Domanski, S. 1972. Basidiomycetes:Aphyllophorales. Polyporaceae I. Mucronoporaceae I. In: Flora Polska (Grzby) 2. 280 p.

Gilbertson, R.L., and L. Ryvarden. 1986. North American Polypores. V. 1. Abortiporus-Lindtneria. Fungiflora, Oslo. 433 p.

Goldstein, D., and R.L. Gilbertson. 1981. Cultural morphology and sexuality of *Inonotus arizonicus*. Mycologia 73: 167-180.

Rayner, A.D.M. and N.K. Todd. 1977. Intraspecific antagonism in natural populations of wood-decaying basidiomycetes. J. Gen. Microbiol. 103: 85-90.

Rayner, A.D.M., and N.K. Todd. 1978. Polymorphism in *Coriolus versicolor* and its relation to interspecific antagonism. Trans. Brit. Mycol. Soc. 71: 99-106.

Toole, E.R. 1961. Rot entrance through dead branches of southern hardwoods. For. Sc. 7: 218-226.

Monitoring Electrical Resistance in Canyon Live Oak Using a Shigometer[1]

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Abstract.–Shigometry was used to evaluate the health of a canyon live oak (*Quercus Chrysolepis* Liemb.) forest. By measuring electrical resistance (ER) in a tree, the shigometer was used to evaluate individual tree health in a study at Skinner Ridge, San Bernardino National Forest, in southern California. Baseline information was collected from 43 randomly selected trees in order to determine an effective sampling methodology and to develop a standard ER reading for healthy trees. The number of samples needed per tree was evaluated. Eight spots were measured per tree. They included the north, south, east, and west aspects at the base and at breast height (bh) – about 15 cm and 1.3 m above the rootcrown, respectively. Electrical resistance in trees, by aspects and bh and bole location, was generally similar, however these ER values did vary among trees. Basal measurements were slightly lower than bh values, but not significantly so – the mean and median differences were about 1 Kohm. Measurements during August 1988 had an average ER reading of 13.3 Kohms. Median ER values for the eight tree spots were between 12 and 14; interquartile ranges were between 2 and 6 Kohms. Apparently, aspect and bole location are not significantly different for sampling purposes in undamaged, healthy, canyon live oaks. And, two or three replicate Shigometer readings per tree should be a sufficient sample.

INTRODUCTION

Forest management practices must often rely on subjective estimates of forest health to determine the success of a silvicultural treatment. Management strategies are implemented at the stand level, but are based on individual tree observations. Monitoring tree mortality and changes in diameter growth among treatments gives reliable information, but are generally time intensive. Years may pass before results can be verified (McCreary 1988, Plumb 1981). Therefore, more immediate and less time consuming, yet precise, monitoring techniques are needed to improve and facilitate the forest manager's evaluations.

Electrical resistance (ER), or electrophysiology, has been used to measure plant vigor or pathology (Blanchard and Carter 1979, Tatter 1976, Tattar and Blanchard 1976, Wargo and Skutt 1975, Wilner 1966). By using differential electrical resistance (ER), Shigo et al. (1985) developed a technique – the shigometer – that can be used within a stand of trees to evaluate individual tree health. A modified ohm meter, the Shigometer produces readings based in large measure on the hydration level of the tree cambium. Generally, the more hydrated the tree cambium is, the more vigorous the tree. Each tree species has its own specific range of readings that can be correlated with vitality or injury. Trees stressed from drought, injury, or pathogens normally register higher ER values on the Shigometer than do healthy trees. Because intra-specific readings are affected by weather conditions, tree phenology, and tree diameter (Cole 1979, Davis et al. 1979, Shigo 1985), it is necessary to standardize the ER data from healthy trees. Differences in Shigometer ER readings will be greater among trees in the same stand during periods of phenological change because of inherent differences in individual tree development. Before monitoring with a Shigometer, baseline information must be gathered for each tree species during a specific season or for each phenological change (Shortle et al. 1977, Cole 1980). The most consistent ER data is usually obtained about 2 weeks after spring flush or during summer when tree growth has stabilized.

Forests and other natural areas in southern California are experiencing an increase in multi-use needs and user demand. Expansion of multi-use programs into previously seldom-used vegetation types is being explored. This expansion coupled with the recent interest in California oak species (Pavlik et al. 1991, Whittington and Tietjje 1992) led us to start a multi-phase study in a canyon live oak (*Quercus chrysolepis* Liemb.) forest on the San Bernardino National Forest, in southern California. In one part of this study we used a Shigometer to measure oak community response to different silvicultural treatments.

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This paper reports on baseline ER data that will be used for standardizing future Shigometer readings in Canyon live oak, and an evaluation of aspect, breast height, and tree base, and determine if vigorous basal sprouting affected the measurements.

METHODS

Data were collected from trees in a closed-canopy canyon live oak forest, on the north slope of Skinner Ridge (1500 m elevation), on the San Bernardino National Forest in southern California, in August 1988. Slope ranged from quite steep (35 degrees) and convex, to moderate and concave. The site was previously burned by wildfire about 100 years ago. The forest had a stand basal area of 54 m^2/ha and was composed of trees that were 3 to 19 meters tall and 3 to 37 cm in diameter.

We randomly selected 43 trees from 3 plots (30 m by 40 m) in each of three blocks and sampled them with a Shigometer. Electrical resistance readings were recorded for eight different spots per tree--four bole measurements at breast height (bh) and four measurements around the base of each tree at each aspect (fig.1). Basal measurements were taken to determine if ER readings were affected by the presence of root zone sprouting, which commonly occurs in canyon live oak trees (Hannah 1987). Sprouts were counted in the basal zone and on the bole to 2 m above the basal zone.

Canyon live oak trees have relatively tough, thin bark. Shigometer pins with a short shaft (4.5 cm) were better suited for this species and were preferentially used in the Shigometer measurements. Occasionally the standard 7.5 cm size pin was needed for larger trees that had thicker bark.

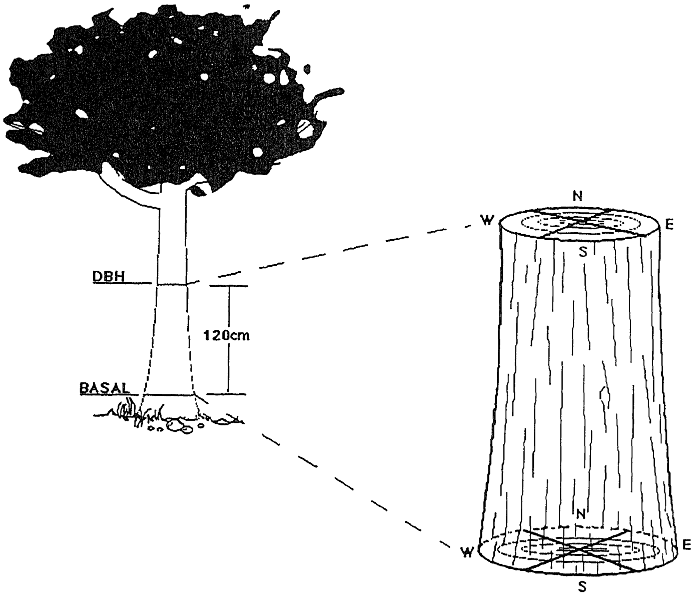

Figure 1.–Each test tree was sampled by the Shigometer at eight different spots on the bole and base.

During our sampling, temperature and humidity readings were monitored among dates. Relative humidity (RH) was higher in plot 1 (RH=63%)than in the other two plots (plot 2, RH=27%;and plot 3, RH=33%).

Summary statistics, including the so called non-parametric variety – medians, and quantiles – were analyzed for the data at the block level, and at the pooled stand level. Welch's approximation to the t-test (Best and Rayner 1987) was used in situations that would call for a t-test, because we had no reason to suspect equality of variances. Correlations were tested with Kendall's tau, because we had no reason to suspect linear relationships. Box and Whisker plots were used to illustrate the distributions of data because of the wealth of information contained in

Table 1. Average Shigometer readings per aspect at bh (breast height,--1.3m) and base of the sampled canyon live oak trees on Skinner Ridge, San Bernardino National Forest, California.

	Electrical resistance (Kohms)								
	Bh				Base				Average
Block	North	South	East	West	North	South	East	West	of mean
1 Mean	12.929	12.00	11.500	12.071	12.071	10.929	11.643	12.214	11.92
Median	13.000	12.000	11.000	12.500	11.500	10.500	11.000	11.500	
2 Mean	13.067	12.733	12.200	12.200	11.600	11.800	12.200	11.933	12.14
Median	13.000	13.000	13.000	13.000	11.000	12.000	11.000	12.000	
3 Mean	17.133	16.200	15.800	16.200	14.600	15.400	15.333	14.867	15.67
Median	16.000	16.000	16.000	15.000	14.000	15.000	15.000	15.000	
All Mean	14.409	13.682	13.205	13.523	12.773	12.750	12.909	13.023	13.28
Median	14.000	14.000	14.000	13.000	13.000	12.500	12.000	13.000	

Table 2. Differences in Shigometer readings between bh (breast height--1.3 m) and base, by block and aspect, (interquartile ranges were between 2 and 6 Kohms), Skinner Ridge, San Bernardino National Forest, California.

		Electrical resistance			
		Differences (bh-base)		Interquartile range	
Block	Aspect	Mean	Median	Bh	Base
1	North	0.857	1.000	5	6
	South	1.071	1.500	4	4
	East	-0.143	0.000	6	6
	West	-0.143	0.000	4	2
2	North	1.467	1.000	4	3
	South	0.933	1.000	4	2
	East	0.533	0.000	5	2
	West	0.267	0.000	3	5
3	North	2.533	2.000	5	2
	South	0.800	1.000	4	4
	East	0.467	1.000	4	5
	West	1.333	1.000	4	4
All	North	1.636	1.000	4	5
	South	0.932	1.000	5	4
	East	0.295	0.000	4	4
	West	0.500	0.000	4	4

them; these plots utilize quantiles – particularly the median, and the quartiles – to demonstrate the spread, symmetry, and central tendency of data.

RESULTS

The bulk of the electrical resistance measurements from individual trees were from 9 to 18 Kohms (based on interquartile values), although values ranged from a minimum of 5 Kohms to a maximum of 22 Kohms. The study level average ER value per tree was 13.3 Kohms, however, averaged ER readings varied among blocks: 11.92 block 1, 12.14 block 2, and 15.67 Kohms blocks 3 (Table 1).

Electrical resistance at the tree base was about 1 Kohm lower than at bh (Table 2). The range in ER values for each of the eight sites per tree was slight, as suggested by the interquartile ranges, which were between 2 and 6 Kohms (fig. 2). The interquartile range is the difference between the 75th and 25th percentiles of the ordered data values. Differences among aspects at a given location also were not significant (Table 4).

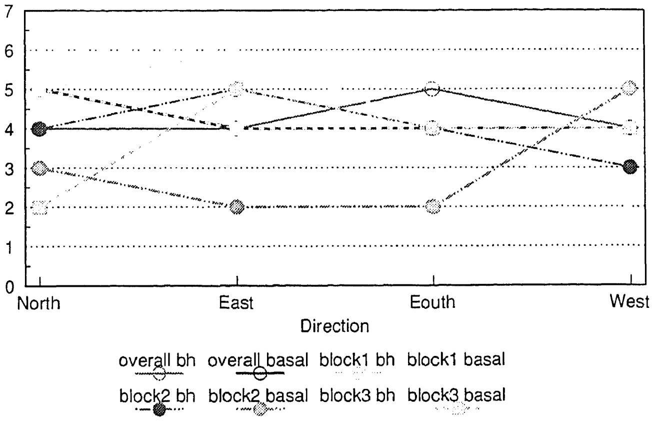

Figure 2.–Interquartile ranges of Shigometer readings by block and aspect.

Differences in ER between base and bh within aspects were generally not statistically significant (Table 3.), but, north aspect differences were significant at the 5 percent level for blocks 2 and 3. Trees in block 3 generally had higher ER readings than the other two blocks at all eight spots per tree (fig. 3).

The correlation of the basal ER readings to the observed sprouting activity was weak (Table 5.), but consistently negative. And basal sprout density was highly correlated with bole sprout density over the first 6 m of bole above the base (Table 5).

CONCLUSIONS

Tree measurements by the Shigometer, by aspect and bole location did not differ significantly, except for the significant difference between bh and base for north aspect readings in blocks 2 and 3, which suggests that perhaps the north aspect should be avoided. Colder temperatures may affect the distribution of electrolytes on that side of the tree. The slightly higher spread in ER readings obtained in plot 1 may correspond to a differential response to a high relative humidity reading for that sampling date. Although the lower extremes of ER for block 1 are lower than for the other blocks (fig. 3), mean values are similar to these for block 2. The higher ER average in block 3 did not have similar RH correlations and could be related to an increase in tree stress (Wargo and Skutt, 1975) caused from increased competition due to a higher density of trees found in this part of the forest.

Since measurements from all eight spots were not significantly different, the eight readings taken per tree during this study were excessive and can probably be reduced to two or three when monitoring healthy trees.

The baseline value determined by Shigometer readings in August for canyon live oak trees was about 13 Kohms. This value should be supplemented by values obtained for all four seasons to ascertain if the vigor of canyon live oak can be completely charac-

Table 3. Bole vs basal shigometer readings. Probabilities derived from Welch's approximation to the t-test.

	North	East	South	West
Across blocks	0.00795	0.32973	0.09485	0.21923
Block 1	0.24659	0.54749	0.18443	0.55982
Block 2	0.05498	0.26689	0.13383	0.38475
Block 3	0.00417	0.29427	0.23485	0.09777

Table 4. Probabilities reflecting significant differences at the 95 percent level among aspects for basal and bh (breast height-1.3 m) locations: probabilities derived from Welch's approximation to the t-test, Skinner Ridge, San Bernardiational Forest, California.

		Differences among aspects Probabilities							
		Bh				Base			
Block	Aspect	North	East	South	West	North	East	South	West
1	North	******	0.112259	0.232411	0.200939	******	0.369454	0.165469	0.547953
	East		******	0.648757	0.702225		******	0.250479	0.699922
	South			******	0.524403			******	0.911918
2	North	******	0.190358	0.351342	0.168888	******	0.534864	0.591199	0.642392
	East		******	0.730700	0.500000		******	0.564121	0.619821
	South			******	0.244537			******	0.554817
3	North	******	0.070280	0.184044	0.182907	******	0.793392	0.786961	0.615213
	East		******	0.680291	0.681440		******	0.524026	0.324976
	South			******	0.317553			******	0.317553
All	North	******	0.042986	0.155428	0.099905	******	0.583744	0.486407	0.654543
	East		******	0.754178	0.693516		******	0.408368	0.569454
	South			******	0.408095			******	0.657695

terized by electrical resistance (Cole 1979, Davis et al., 1979, Wilner 1966).

ACKNOWLEDGEMENT

We thank Steve Bunyak for his assistance in collecting and processing the field data.

Table 5. Kendall's TAU correlations between basal Shigometer readings and basal sprout density, and between bole sprout density and basal sprout density.

	north basal	east basal	south basal	west basal	bole sprout density
basal sprout density	-0.173	-0.267	-0.224	-0.238	0.924

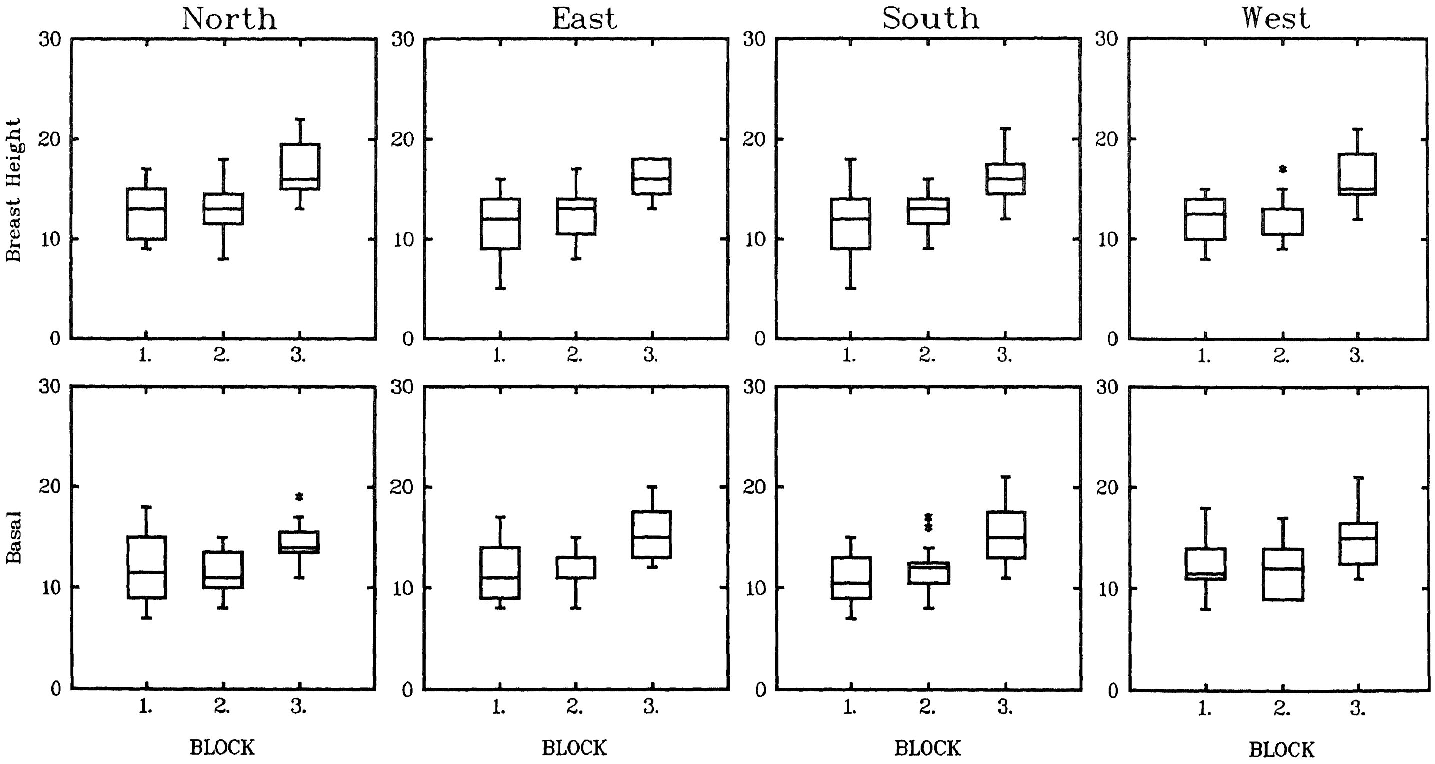

Figure 3.–Box and whisker plots of electrical resistance for aspect and bole locations by block.

LITERATURE CITED

Blanchard, R.O.; Carter, J.K. 1980. Electrical resistance measurements to detect Dutch elm disease prior to symptom expression. Canadian Journal of Forest Research. 10: 111-114.

Davis, W.; Shigo, A.; Weyrick, R. 1979. Seasonal changes in electrical resistance of inner bark in red oak, red maple and eastern white pine. Forest Science. 25(2): 282-286.

Best, D.J.; Rayner, J.C.W. 1987. Welch's approximate solution for the Behrens- Fisher problem. Technometrics. 29(2): 205-210.

Cole, D.M. 1980. Within-stand comparisons of inner bark electrical resistance in lodgepole pine – the bark moisture factor. Forest Science. 26(2): 309-312.

Hannah, Peter R. 1987. Regeneration methods for oaks. Northern Journal of Applied Forestry. 4: 97-101.

McCreary, D. 1988. Brown trees bounce back. Oaks 'N Folks. Cooperative Extension, USDA UC Berkeley, CA. 3(1): 1.

Pavlik, B.M.; Muick, P.C.; Johnson, S.; Popper, M. 1991. Oaks of California. Cachuma Press Inc. 184 pp.

Plumb, T.R.; Gomez, A.P. 1983. Five southern California oaks: identification and postfire management. Gen. Tech. Rep. PSW-71. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 56 pp.

Plumb, T.R.; McDonald, P.M. 1981. Oak management in California. Gen. Tech. Rep. PSW-54. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 11 pp.

Shigo, A.L.; Shortle, W.C. 1985. Shigometry: Agric. Handb. 646. Washington, DC: U.S. Department of Agriculture. 49 pp.

Shortle, W.S.; Shigo, A.L.; Berry, P.; Abusamara, J. 1977. Electrical resistance in tree cambium zone: relationship to rates of growth and would closure. Forest Science. 23: 326-329.

Tattar, T.A. 1976. Use of electrical resistance to detect Verticillium wilt in Norway and sugar maple. Canadian Journal of Forest Research. 6: 499-503.

Tattar, T.A.; Blanchard, R.O. 1976. Electrophysiological research in plant pathology. Annual Review of Phytopathology. 14: 309-325.

Wargo, P.M.; Skutt, R.H. 1975. Resistance to pulsed electric current: an indicator of stress in forest trees. Canadian Journal of Forest Research. 5: 557-561.

Whittington, J.M.; Tietje, W.D. 1992. Saving native oaks calls for planning. California Agriculture. 46(2): 20-23.

Wilner, J. 1966. Changes in electric resistance of living and injured tissues of apple shoots during winter and spring. Canadian Journal of Plant Science. 47: 469-475.

Field Trip Summary

Duane A. Bennett, Forester
Sierra Vista Ranger District

A field trip to view management practices and issues, as well as past and current research projects relating to the oak woodlands surrounding the Sierra Vista area took place on April 29, 1992. James Abbott, Forest Supervisor, Coronado National Forest, chaired the session in which participants listened to short presentations, viewed research and management projects, and had opportunities to question and comment at each of the six stops.

The first stop was at Montezuma Pass, in the Coronado National Memorial. Here, the participants listened to Park Superintendent Ed Lopez explain about the Memorial's inception, it's mission, and anticipated impacts from an increasing local population and a possible opening of an international border crossing near the Memorial's boundary, which would link the towns of Sierra Vista and Cananea, Sonora, Mexico. Dick Anderson, from the Chiricahua National Monument near Wilcox, Arizona, followed Ed in presenting information about the management of the oak woodlands within National Park Service jurisdiction in southeast Arizona. Dick explained about research in the National Parks and how it is implemented. He also talked about the 1988 Peak Fire, which originated in Mexico and burned across the border into and through the Park. Dick addressed the effects of the fire (fire intensity, fireline scars, etc.), with respect to erosion, visual quality, wildlife habitat, and several other environmental concerns.

The second stop was in the Copper Canyon area on the Sierra Vista Ranger District (SVRD), Coronado National Forest. At this location, Duane Bennett, Forester, SVRD, spoke about current research studies in the area's oak woodlands, and others that have been completed in the last several years. In particular, Duane discussed a recent study in which he and Ramzi Touchan, University of Arizona, investigated the effects of thinning oak coppice to several intensities at different time intervals. Following Duane were Mary Lou Fairweather, from the USDA Forest Service, Forest Pest Management Group at Flagstaff, Arizona, and Robert Gilbertson, from the University of Arizona. Mary Lou discussed the common mistletoe that infects the oaks in the local area, its adverse effects on tree health, its control through natural and prescribed fires, and its benefits to the bird population. Robert Gilbertson discussed diseases that commonly affect the oak species in southeastern Arizona, including several types of fungi and foliage diseases. Dr. Gilbertson pointed out that the oaks in the area also serve as alternate hosts for the Southwestern cone rust.

Mary Lou Fairweather discusses mistletoe in the oak woodlands.

Campini Mesa served as the setting for the third stop, where Laura Dupee, Range Conservationist, SVRD, explained local range management issues and concerns. Topics included the cattle vs. quail habitat issue, range management plans, and erosion concerns. Tom Deecken, Wildlife Biologist, SVRD, explained concerns about grazing effects on threatened, endangered, and sensitive plant and animal species present on the district, and the opportunity to work with the permittee to protect or possibly enhance habitat through the allotment management plan. After those presentations, Laura guided the group to a nearby erosion control project that is partially completed. Problems in design and installation were pointed out, and possible corrective measures were suggested by the group.

The fourth stop was at Parker Canyon Lake, where Dennis Brandolino, Recreation and Lands Staff, SVRD, discussed the history of the lake and associated developments. Dennis explained how the land on which the lake now lies was exchanged from private ownership to federal, and through cooperation with the Arizona Game and Fish Department (AGFD), the lake was created in the mid-1960's. Increased use over the years warranted further development of adjacent recreational facilities, which has culminated in the latest improvement, the $700,000 Merritt Point marina improvement. Dennis also mentioned that the lake was stocked regularly by the AGFD with trout, bass, and catfish. Also at that stop, Tom Deecken discussed cooperative projects completed with the help of local groups. These projects included submersing "banana trees" and other structures that create habitat and protection for small fish.

Stop five was on the "Research Ranch," which is actually National Forest land that has been removed from grazing for several decades. Jeanne Wade, District Ranger, SVRD, discussed the cooperative use of this land with the Nature Conservancy for research purposes. The effects of "non-use" by cattle was among the many studies ongoing and completed on the Research Ranch. Jeanne also spoke of general grazing problems, issues, and challenges, such as the urbanization of private lands within and adjacent to the National Forest. Jeanne was joined by Bill Wilcox, Range Staff, SVRD, who also discussed past vegetative manipulation on district rangelands, fire effects on the range/woodland interface, stocking levels and their effect on vegetation change, and the need for evaluating current trends on rangelands. Bill Block, Biologist, Rocky Mountain Forest & Range Experiment Station, discussed oak woodland wildlife habitat and the changes that have occurred over time. Bill also expressed the need for further research in this type, including the effects of fire suppression, fuelwood harvesting, and grazing on the woodlands. Bill increased the awareness of the group on how important the oak woodlands are for habitat they provide by listing approximately 20 species of birds he observed during the previous portion of the trip. Tom Deecken also stressed the importance of the oak woodland-grassland interface to wildlife, and that further studies are needed.

The final stop was on the Fort Huachuca Military Reservation. Post Forester John Miller and Post Wildlife Biologist Sheridan Stone discussed similarities in management goals with other State and Federal agencies, but also pointed out differences in management practices when operating on a Department of Defense installation. John and Sheridan informed the group about the constant need to juggle Federal law requirements outlined in the National Environmental Policy Act (NEPA) and the Federal Land Policy & Management Act (FLPMA) with military procedures and objectives. Other projects currently undertaken on the Fort included fuelwood sales, fire salvage sales, wildlife surveys, big game animal hunts, and wildlife habitat improvements. This discussion took place under several large Emory oaks, which had been pruned of their lower branches that day, as part of an ongoing fuel break project. Due to the frequency of fire starts because of the military operations and the lack of grazing, it was feared that if a fire started in or near this area, suppression would be difficult and these large trees may be killed.

This field trip served as an excellent forum to discuss the different management practices and research projects exhibited along the route, as well as in all other areas of the oak and associated woodlands. The participants asked questions about, and commented on, the management issues and concerns brought up, such as fuelwood harvesting, grazing, and recreational use. The group also recommended several research opportunities in the woodlands to better understand the effects of current management practices on the ecosystem. These recommendations are included in the "Future Research and Management Needs" paper presented elsewhere in these proceedings.

Títulos y Resúmenes en Espanol

Traducido por
Heidi Romero-Schmidt y Alfredo Ortega-Rubio

NECESIDADES DE INVESTIGACION Y MANEJO EN LOS BOSQUES DEL SUROESTE DE LOS ESTADOS UNIDOS DE NORTEAMERICA Y EL NORTE DE MEXICO.

Peter F. Ffolliott, Gerald J. Gottfried and Duane A. Bennett.

Resumen:

3 listas de necesidades de investigación y manejo en los bosques del Suroeste de los Estados Unidos de Norteamérica y el Norte de México son presentadas.

La tercera lista contiene sugerencias y recomendaciones hechas por los participantes en este simposio de 1992. Esas 3 listas, y particularmente aquella ofrecida por los participantes, pueden ser útiles en el establecimiento de una agenda para la investigación y manejo en el futuro próximo.

EL TRATADO DEL LIBRE COMERCIO: IMPLICACIONES PARA LA AGRICULTURA Y PARA LOS RECURSOS NATURALES.

Harry Ayer.

Resumen:

El Tratado del Libre Comercio de Norteamérica (TLCN) actualmente está siendo negociado por Estados Unidos, México y Canadá y se espera que sea firmado en 1993. El TLCN es principalmente para reducir las barreras para el comercio - incluyendo tarifas, requrimientos de licencias, regulaciones de mercadotécnia y regulaciones fitosanitarias - entre los 3 países. La agricultura y las actividades forestales serán afectadas. El impacto sobre sectores de mercancías particulares dependerá del trabajo intensivo de la producción y operaciones de cosecha, las diferencias de las tasas salariales entre México y los Estados Unidos, la capacidad productiva de mercancías particulares de cada país, y el nivel corriente de las barreras de comercio. Se espera que el TLCN incremente la producción y exportación de vegetales y con el tiempo posiblemente de cítricos y carne de México a los Estados Unidos. El TLCN probablemente incrementará la producción de granos, cítricos, manzanas, productos lácteos y pequeños productos forestales en los Estados Unidos y su exportación a México, a menos a corto plazo. El TLCN no impactará significativamente la producción de algodón ni en México ni en Estados Unidos. El TLCN puede indirectamente a través de su impacto sobre los ingresos de los consumidores en México incrementar la producción de alimento para el ganado mexicano, pero no incrementará probablemente la exportación de alimentos mexicanos a Estados Unidos.

Finalmente, el TLCN incrementará la demanda de México por leña producida en los estados del Suroeste de los Estados Unidos. Sin embargo ya sea que el TLCN incremente o no el corte de los bosques de encino, esto depende de las políticas de manejo de bosques del Gobierno de los Estados Unidos en las tierras públicas.

VALORES MULTIPLES DE LOS BOSQUES EN EL SUROESTE DE LOS ESTADOS UNIDOS Y EL NORTE DE MEXICO.

Peter F. Ffolliott.

Resumen:

Los valores de los bosques en el Suroeste de los Estados Unidos y el Norte de México para la producción de madera y de ganado, recursos silvestres, manejo de cuencas, y recreación y turísmo son descritos. La mayor parte de estos bosques continuan siendo usados como lo fueron en el pasado. Sin embargo, su manejo responde cada día más a los valores múltiples de estas comunidades boscosas y a los deseos de la gente por estos beneficios múltiples.

ECOLOGIA DE BOSQUES DE ENCINO EN ARIZONA.

Guy R. McPherson.

Resumen:

La investigación autoecológica y sinecológica en los bosques de encino (*Quercus* spp.) de Arizona han sido limitados a relativamente pocos estudios. La mayor parte de la investigación autoecológica se ha enfocado en el encino de emori. (*Q. emoryi*) y en el encino blanco de Arizona (*Q. arizonica*), las dos especies más comunes en esos bosques. Los datos de éstas especies, y de otras de los cuales estaban disponibles, se organizan y se sintetizan en este trabajo, de acuerdo a los estados de historias de vida. La sinecología de los bosques de encino se restringe en su mayor parte a descripciones de conjuntos de especies. Sustentándome ampliamente en evidencias indirectas, yo especulo sobre el papel ecológico de varios disturbios, y la respuesta de los bosques a ellos. Posibles perspectivas para investigación futura son puestas en relieve.

CRECIMIENTO, RENDIMIENTO, Y UTILIZACION DE LOS BOSQUES DE ENCINO EN EL SUROESTE DE LOS ESTADOS UNIDOS.

Peter F. Ffolliott and Gerald J. Gottfried.

Resumen:

Las tasas de crecimiento y subsecuentes rendimientos de los bosques de encino en el Suroeste de los Estados Unidos son comparativamente bajos. La ocurrencia frecuente de árboles con múltiples tallos y de forma irregular limita grandemente su utilización comercial para productos de madera, aunque madera para leña y para cercas se cosecha expresamente para usos locales. Son necesarios inventarios más intensivos para manejar estos bosques en términos de conservación y producción sostenible.

ECOLOGIA DE LOS BOSQUES DE ENCINO EN LA SIERRA MADRE OCCIDENTAL DE MEXICO.

Victor Manuel Hernández, Francisco Javier Hernández y Santiago Solís González.

LOS BOSQUES DE ENCINO Y ENCINO PINO DE BAJA CALIFORNIA SUR: ESTADO PRESENTE Y PERSPECTIVAS DE MANEJO.

Laura Arriaga, Sara Díaz y Carmen Mercado.

Resumen:

El bosque de encino y el bosque de encino-pino de la Sierra de La Laguna en el Sur de Baja California Sur son analizados de acuerdo a su composición de especies, características estructurales y procesos de regeneración natural. Sus aspectos demográficos y sus implicaciones, el manejo silvícola son presentados también para el pino piñonero endémico. Nuestros resultados indican que el recurso forestal que crece en esta zona montañosa no tiene una vocación para la producción de madera por la pequeña área que cubre, y por la escacéz de diámetros y volúmenes comerciales, los cuales son insuficientes para mantener una contínua y rentable extración del recurso forestal del pino de Baja California Sur. Opciones alternativas de manejo se discuten también.

DISTRIBUCION DEL ENCINO "*QUERCUS SPP.*" EN EL ESTADO DE SONORA, MEXICO.

Luis Martínez Islas.

EL VENADO COLA BLANCA DE COUES Y LOS BOSQUES DE ENCINO.

Norman S. Smith y Robert G. Anthony.

Resumen:

La distribución del venado cola blanca de Coues en Arizona está asociada, en parte, con la distribución de los bosques de encino. La dieta del venado cola blanca inlcuye muchas especies de arbustos, árboles, hierbas y pastos encontrados dentro de los bosques de encino y tipo de vegetación ecotonal. Los efectos de las perturbaciones en los bosques de encino sobre el venado cola blanca no son claros. Estudios previos sugieren que la respuesta a la perturbación en la periferia xérica de la zona, puede diferir de la respuesta en el centro de la zona. Estudios del uso del agua y su distribución, la competencia con el venado bura y el ganado, la reproducción, El ámbito-hogareño y de ecología en general indican que el venado cola blanca puede ser muy vulnerable a la perturbación en su zona baja altitudinal.

PRODUCCION DE GANADO Y MANEJO DEL PASTOREO EN LOS BOSQUES DE ENCINO DE ARIZONA.

Mitchel P. McClaran, Larry S. Allen and George B. Ruyle.

Resumen:

El ganado pace en prácticamente todos los bosques de encino en Arizona. La mezcla de pastos de las estaciones cálida y fría, y algunas especies arbustivas proveen un recurso favorable para la producción de ganado. Los sistemas de pastoreo, la crianza en el verano tardío y la complementación de fósforo, proteína y energía pueden mejorar la producción de ganado. El Incremento del desarrollo residencial puede reducir la rentabilidad de la producción del ganado por el aumento de los precios de la tierra, los impuestos sobre las propiedades y las pérdidas del acceso debido a más cercos. Debido a que prácticamente el 80% del pastoreo en los bosques ocurre en tierras federales, el manejo del pastoreo debe adecuarse a usos conflictivos, tales como la vida silvestre, especies raras, reclutamiento de encino y recreación. Esta situación desafía a los manejadores de zonas a desarrollar estratégias para adecuar los usos conflictivos sin la elimiancıón de la integridad económica y biológica, de otros recursos o usos.

EL USO DE ENCINOS POR AVES MIGRATORIAS NEOTROPICALES EN EL SUORESTE.

William M. Block, Joseph L. Ganey, Kieth E. Severson, and Michael L. Morrison.

Resumen:

Nosotros registramos 98 especies de aves migratorias neotropicales en tipos de vegetación que contienen encinos en el Suroeste de Arizona y en el Sureste de California. Los migrantes neotropicales usan esas áreas para crianza y habitats de migración Muy poca similaridad fue encontrada en los grupos de aves neotropicales de California y Arizona. Dentro de Arizona, los conjuntos de aves fueron más similares entre los bosques mixtos de coníferas y los bosques de pino-encino. El uso de encinos para forrajeo varía entre 17.4 % hasta 73.7 % del total de los intentos de forrajeo para las 9 especies estudiadas. Esas aves usan especies de encino en proporciones únicas.

HIDROLOGIA Y MANEJO DE CUENCAS DE LOS BOSQUES DE PINO EN EL SURESTE DE ARIZONA.

Vicente L. López and Peter F. Ffolliott.

Resumen:

Las interacciones entre los procesos hidrológicos, el complejo suelo-vegetación, y las prácticas de manejo en bosques de encino del sureste de Arizona no han sido investigados totalmente. Una razón para esta omisión es la escaséz de cuantificaciones del flujo de las tormentas, la erosión del suelo, y la producción de sedimento para esas áreas. Este trabajo resume los datos climáticos y de suelos representativos de bosques de encino en el sureste de Arizona, examina aspectos de manejo de cuencas, e introduce y discute los procesos hidrológicos y sedimentarios comúnes a ambientes secos con características similares a los bosques de encino.

ECOLOGIA Y MANEJO DE LOS BOSQUES DE PINON JUNIPERO DEL SUROESTE.

Gerald J. Gottfried.

Resumen:

Los bosques de piñon junípero cubren grandes áreas de Arizona y Nuevo México. El manejo de esas tierras varía desde enfatizar un recurso simple hasta el reconocimiento de el valor de esos bosques por un número de recursos valiosos. El manejo apropiado de estos bosques para combinaciones de usos de; madera para leña, pastoreo, vida silvestre y recreación, debe ser basado en información ecológica apropiada. Aunque la información es incompleta, éste artículo intenta describir nuestro conocimiento actual de la ecología (principalmente de las especies de arbóreas) y del manejo de los ecosistemas de bosques de piñon-junípero.

ECOLOGIA Y VALORES DE LOS BOSQUES DE ENCINO DE GAMBELL.

Warren P. Clary and Arthur R. Tiedemann.

Resumen:

El encino de Gambel (*Quercus gambelii* Nutt.) es un componente importante de la vegetación que cubre aproximadamente 3.8 millones de hectáreas del Oeste de los Estados Unidos. Este encino se encuentra en la zona de transición de vida de Merrian, proveyendo el establecimiento de cuencas, hábitats para la vida silvestre, madera para leña y una variedad de otros valores. El encino de Gambel es difícil de remover permanentemente debido a su extensivo sistema subterráneo de tubos interconectados lignificados, rizomas y raíces. La especie tiene considerables valores económicos de conservación y estéticos cuando es manejada en el sitio.

EXTRACCION DE LENA EN EL SURESTE DE ARIZONA.

Duane A. Bennett.

Resumen:

La demanda de leña en el Sureste de Arizona durante los últimos años de los 70's y principios de los 80's se incrementó dramáticamente. Los manejadores de las tierras del Bosque Nacional de Coronado impusieron restricciones en la cosecha para continuar con una extracción sostenible de los recursos madereros. Este trabajo describe el sistema de colecta en un lugar de Sierra Vista Distrito de Manejo. Los detalles sobre la selección del área, criterios de marcado, sistemas de aplicación/permiso y procedimientos de cosecha son discutidos.

VALORES CULTURALES RECREACIONALES Y ESTETICOS DE LOS BOSQUES DE ENCINO.

Judith G. Propper.

Resumen:

Los bosques siempre verdez de encino del sureste de Arizona han sido usados por los grupos humanos por miles de años. Ellos contienen no sólo valores comerciales y para la vida silvestre, sino también valores culturales recreacionales y estéticos, importantes para nuestra sociedad contemporanea. Estos valores necesitan ser tomados en cuenta en función de las necesidades de manejo y beneficio de ambientes de los bosques de encino.

UTILIZACION DE LA MADERA PARA CONSTRUCCION, LENA, Y PRODUCTOS FORESTALES NO-TRADICIONALES EN CALIFORNIA, ARIZONA Y NUEVO MEXICO.

Dean W. Huber.

Resumen:

En todas partes del Oeste de los Estados Unidos, las especies maderables suaves dominan los recursos forestales y la subsecuente industria de productos maderables. Aunque subútilizados, existen ventas de madera para construcción, leña y otros productos forestales no-tradicionales de las tierras boscosas del suroeste de los Estados Unidos. La mejor comprensión de industrias basadas en productos no-tradicionales del bosque, podría enfatizar el apoyo para la estabilización de comunidades rurales y su desarrollo. Una mejor utilización de la madera, la leña y otros productos forestales no tradicionales puede llegar a ser también una parte integral de las prácticas de manejo de tierra y mejoramiento de los ecosistemas.

COORDINACION, GANADERA-VIDA SILVESTRE EN LOS BOSQUES DE ENCINO DEL BOSQUE NACIONAL DE CORONADO.

Larry S. Allen.

Resumen:

El pastoreo del ganado doméstico es un uso de la tierra antiguamente establecido en los bosques de encino del Sur de Arizona, y el estilo de vida ranchero que ésta industria soporta es una parte importante de la cultura y herencia del área. La contribución del ganado a la economía local, aunque algo opacada por la recreación relacionada a la vida silvestre, es significativa. La experiencia indica que la resolución del número de ganado es escencial para el manejo del hábitat en relación a la vida silvestre. Quizás el nivel de manejo de la zona es más crítico.

El pastoreo por ganado puede ser compatible con la calidad del hábitat para la vida silvestre en esos hábitats, si nosotros identificamos los factores clave del hábitat para la vida silvestre y los incorporamos dentro de los planes de manejo de la zona. “ El Proceso Integrado de Manejo de Recursos” del Servicio de Bosques es un instrumento útil para alcanzar esta coordinación.

MANEJO Y PRACTICAS SILVICULTURALES APLICADAS A LOS BOSQUES DE PINO ENCINO EN DURANGO, MEXICO.

Victor Manuel Hernández, Francisco Javier Hernández y Santiago Solís González.

ECOLOGIA Y MANEJO DE LOS BOSQUES DE ENCINO DE CALIFORNIA.

J.W. Bartolome and R.B. Standiford.

Resumen:

Las tierras maderables de California, dominadas por encinos cubren aproximadamente 10 millones de acres. Esas tierras han sido alteradas significativamente por las actividades humanas incluyendo quema, aclareamiento, cultivo, pastoreo de ganado e introducciones de plantas exóticas. En 1986 la Universidad de California y el Departamento Forestal y de Protección de Incendios de California iniciaron un bien cimentado programa de investigación y educación a 10 años que enfrentará problemas con regeneración de encino, protección de hábitats para la vida silvestre, urbanización, estrategias efectivas de manejo y monitoreo. Este exitoso programa ofrece algunas lecciones útiles para el desarrollo de iniciativas comprensivas de protección integral de los recursos naturales.

COMPOSICION DE ESPECIES EN LAS COMUNIDADES DE BOSQUES EN EL SUROESTE.

Rex D. Pieper.

Resumen:

Las comunidades de encinal y de piñon-junípero en el Suroeste de los Estados Unidos y el Norte de México son estructuralmente complejas debido a las variaciones en clima, topografía, suelo, uso de la tierra y afinidades fitogeográficas. Un adecuado manejo y uso de estas frágiles comunidades de plantas, requiere un conocimiento básico de la ecología y florística de las diferentes comunidades. Este trabajo presenta una comparación basada en estudios separados en Nuevo México, el Sureste de Arizona y el Noroeste de Chihuahua, México.

En el Oeste y en el Centro de Nuevo México, el estrato arbóreo es dominado por especies de *Juniperus*. *Juniperus monosperma* es la especie de junípero más abundante en Nuevo México central, en las Montañas de Sacramento y *J. deppeana* es más abundante en el bosque Nacional Gila, en el Oeste de Nuevo México. En las montañas de Huachuca y Sierra Madre, la composición de especies de *Juniperos* es mucho menor. El taxa *Pinus* de los bosques cambia desde *P. edulis* en Nuevo México hasta *P. cembroides* en Arizona y Chihuahua. Las especies de encinos son en su mayor parte en arbustivas (principalmente *Quercus undulata*) en las Montañas de Sacramento pero son generalmente árboles pequeños en el Oeste de Nuevo México, sureste de Arizona y el norte de Chihuahua. *Quercus arizónica* es relativamente abundante en las tres localidades oeste, pero no en las Montañas de Sacramento. *Quercus gricea* es abundante en el oeste de Nuevo México y en el norte de Chihuahua, pero no en las Montañas de Huachuca. Varias especies de pastos incluyendo *Bouteloua gracilis*, *B. curtipendula*, *Muhlembergia emersleyi* y *Piptochaetium fimbriatum* están ampliamente distribuidas en estos bosques.

USO DEL ENCINO Y BOSQUES ASOCIADOS POR LOS BUHOS MOTEADOS MEXICANOS EN ARIZONA.

Joseph L. Ganey, Russell B. Duncan and William M. Block.

Resumen:

Aunque el búho moteado es frecuentemente asociado con bosques de coníferas, los bosques de encino y bosques asociados también proveen hábitats para los buhos moteados. En Arizona, los búhos moteados mexicanos son residentes todo el año en los bosques Madrianos de encino-pino, bosques de encino y bosques de pino ponderosa-encino Gambel, y algunos búhos moteados invernan en los bosques de piñon-junípero. Los encinos y bosques asociados presentan desafíos únicos de manejo para los manejadores de recursos encargados de mantener poblaciones viables de búhos moteados mexicanos.

LA IMPORTANCIA DE LOS BOSQUES DE LA SIERRA DE LA LAGUNA PARA LA CONSERVACION DE ESPECIES ENDEMICAS DE MEXICO.

Alfredo Ortega, Heidi Romero y Cerafina Arguelles.

Resumen:

En todo el Estado de Baja California Sur existe solamente un lugar donde es posible encontrar bosques de encinos: en La Sierra de La Laguna. La importancia de tales bosques desde el punto de vista biológico y socioeconómico son discutidos. La mayor parte de la precipitación pluvial del Estado ocurre en tales bosques lo cual permite la presente distribución de las principales agrupaciones humanas de Baja California Sur y sus principales posibilidades de desarrollo. También, tales ecosistemas contienen la mayor parte de la diversidad biológica de todo el Estado. Debido a la alta incidencia de endemísmos en tales bosques estos pueden ser también considerados como muy importantes para la herencia de la humanidad.

DIVERSIDAD ESTRUCTURAL EN BOSQUES DE ENCINO DEL SURESTE DE ARIZONA.

James W. Sharman and Peter F. Ffolliott.

Resumen:

Las medidas de 3 características fueron usadas como indicadores de sobreposición de estructura en cuatro sitios de bosques de encino. Tres áreas cosechadas a diferentes tiempos e intensidades fueron comparadas con un área no perturbada para evaluar los efectos de la cosecha en varios atributos estructurales, sobre las existencias de los bosques. Fueron encontradas diferencias para algunas características estructurales de los bosques entre las áreas cosechadas y el área no cosechada. Los cambios estructurales persisten, como la prolífica producción de retoños delgados que inicialmente producen más bien árboles en forma de arbusto, a los cuales parece que les toma un tiempo relativamente largo alcanzar una forma y una altura madura.

ESTABLECIMIENTO DE ENCINOS A TRAVES DE SEMILLA EN LOS BOSQUES DE ENCINO DE CALIFORNIA.

Theodore E. Adams Jr., Peter B. Sands, William H. Weitkamp, and Neil K. McDougald.

Resumen:

Los factores que contribuyen al pobre establecimiento del encino azúl (*Quercus douglasii*) y del encino del valle (*Q. lobata*) en los bosques de encino de california fueron estudiados en una serie de experimentos a través de semillas de bellotas iniciados en 1985. La exclusión de grandes herbívoros permite el exámen de las interferencias por herbáceas y de la depredación por pequeños mamíferos e insectos. La interferencia por herbáceas fue el factor más importante. El control de éstas, incrementa la emergencia de la semilla del encino azúl en casi 80% y de la semilla del encino del valle en un 40%. La sobrevivencia, expresada como un porcentaje de las bellotas plantadas fué mejorada significativamente por la eliminación de hierbas en los sitios tanto para el encino azúl como para el encino del valle. Los datos limitados sugieren que la sobrevivencia diferencial se mantiene sobre el tiempo como un declinamiento general de la sobrevivencia. Con pocas excepciones, la adición de una pantalla de protección para desalentar la predación incrementa significativamente la sobrevivencia y el crecimiento. Se sospecha que la sombra provista por las ventanas de las cajas-pantalla esta contribuyendo en una forma positiva, no medida. La interacción entre el control de herbáceas y protección parece desarrollarse con el tiempo.

ESTRUCTURA DE UNA TABLA DE RENDIMIENTO DENSO-VARIABLE PARA EL ENCINO DE EMORI.

Patrick Fowler and Peter F. Ffolliott.

Resumen:

Una tabla de rendimiento denso-variable desarrollada para usarse en lotes de encino de emori del Sureste de Arizona tiene aplicaciones para los modelos de crecimiento y rendimiento. Las entradas al modelo incluyen edad, índice de sitio y área basal, variables obtenidas fácilmente de los datos del inventario. Sin embargo, son necesarias pruebas futuras de la tabla de rendimiento denso-variable, antes de que sea aplicada de forma más general.

TEMPERATURAS DE SUELO RELACIONADAS AL INCENDIO PRESCRITO EN LOTES DE PINO PONDEROSA EN EL VALLE DE YOSEMITE QUE INCLUYE EL ENCINO NEGRO DE CALIFORNIA.

Stephen S. Sackett, Sally M. Haase, and Gloria M. Burke.

Resumen:

El incendio prescrito ha sido activamente llevado a cabo en el Parque Nacional de Yosemite desde el principio de los años 70's. En los últimos dos años se ha desarrollado un esfuerzo para identificar un efecto no observado del incendio, llamado temperaturas de suelo. Los fuegos en los lotes de la secuoya gigante (*Sequoiadendron giganteum* [Lindl.] Buchhorlz) y coníferas mescladas y lotes de pino ponderosa (*Pinus ponderosa* Dougl. ex Laws.) han sido ampliamente documentados. En dos de los lotes de pino ponderosa quemados, árboles de encino negro de california (*Quercus kelloggii* Newb.), estuvieron presentes. Las temperaturas del suelo medidas cercas de las bases de esos 2 árboles reflejan flujos de calor completamente diferentes. El calor no penetra a través del suelo donde leña del encino negro domina el microhabitat. En el otro caso, el árbol de encino fue más pequeño y la leña tirada de los pinos que lo rodeaban dominaba la composición del piso del bosque. El calor en este sitio fue substancialmente más grande y a mayor profundidad. Una preponderancia de hojas de encino en la composición total del piso del bosque parece reducir la combustibilidad del piso del bosque, resultando así en un calentamiento menor del suelo.

GRAVEDAD ESPECIFICA Y PROPIEDADES FISICAS ESTIMADAS DEL ENCINO DE EMORI EN EL SURESTE DE ARIZONA.

John K. Maingi and Peter F. Ffolliott.

Resumen:

La gravedad específica promedio del encino de emori (*Quercus emoryi* Torr.) estimada de 115 núcleos de incremento fué de 0.567 ± 0.011. La gravedad específica de los núcleos de incremento fué un predictor de la gravedad específica promedio del árbol. De los árboles y de las variables probadas, solamente el diámetro a la altura del pecho y el diámetro del cuello de la raíz estuvieron correlacionados con la gravedad específica del núcleo de incremento. Las propiedades físicas estimadas de encino de emori fueron menores que aquellos reportados para el encino de gambel (*Quercus gambellii* Nutt.).

EFECTOS DEL FUEGO EN DOS ESPECIES DE ENCINO, *QUERCUS EMORYI* AND *Q. OBLONGIFOLIA* EN EL SURESTE DE ARIZONA.

Anthony C. Caprio and Malcolm J. Zwolinski.

Resumen:

Quercus emori y *Q. oblongifolia* fueron muestreados en un bosque Madriano siempre-verde recientemente quemado, para determinar hasta que punto fueron afectados por el fuego y si la respuesta a la quema difiere entre especies. El muestreo fue llevado a cabo en la cuenca del Molino, en la pendiente sur de las Montañas de Santa Catalina, al Sureste de Arizona, en el verano de 1985 siguiendo un fuego ocurrido en junio de 1983. Un total de 544 árboles fueron examinados buscando los efectos del fuego por clase de tamaño en 3 sitios donde ambas especies ocurren simpátricamente. Los efectos del fuego, definidos como sobrevivencia de árboles con la corona viva, árboles muertos en su punta, o árboles muertos fueron registrados para cada individuo, adicionalmente, el número de retoños por árbol fue registrado en pares de cuadrantes, quemados y no quemados en cada sitio. Los árboles en los cuadrantes quemados corresponden a un subconjunto de aquellos examinados para efectos del fuego. Fueron encontradas diferencias en los efectos entre especies y por clase de tamaño pero no por su sitio. La mortalidad total fué baja (11-15%) para ambas especies, sin embargo, pocos individuos de *Q. oblondifolia* murieron o fueron muertos en la punta en las clases de talla grande (mayor de 30 cms de diámetro) comparados con *Q. emori*. En los cuadrantes quemados al menos 94% de los árboles vivos de ambas especies producen retoños mientras esto varía de 8 a 16% en los cruadrantes no quemados. *Q. emori* fué un productor de retoños más vigoroso iniciando en un promedio de 15 a 23 retoños por árbol, mientras que *Q. oblondifolia* produce de 3 a 11. La mayor resistencia de *Q. oblondifolia* al fuego puede ser importante para su supervivencia en un hábitat de sabana de pastos secos, donde los incendios de rápidos movimientos de comparativamente alta intensidad pero corta duración, son relativamente frecuentes. La mejor habilidad retoñadora de *Q. emori* puede ser una ventaja de supervivencia en un hábitat que frecuentemente tiene un cerrado dosel de árboles y arbustos, donde los fuegos son de frecuencia decreciente pero de alta intensidad y larga duración y pueden comúnmente causar la muerte de tallos por arriba del suelo.

ESTIMACIONES DEL VOLUMEN Y BIOMASA PARA LAS ESPECIES DE TIERRAS ARIDAS.

David C. Chojnacky.

Resumen:

Ecuaciones de volumenes fueron desarrolladas para los *Quercus arizonica*, *Q. emoryi*, *Q. hypoleucoides*, *Q. oblongifolia*, *Q. gambelii* y especies no identificadas de *Quercus* siempre verdes de Arizona y Nuevo México. Las ecuaciones fueron construídas a partir de volumenes medidos visualmente y de mediciones de diámetro y altura. Las estimaciones de volumen incluyen la madera y la corteza de todas las ramas de 3.8 cms. (1.5") y más grandes. La gravedad específica disponible para varias especies, se utilizó para convertir las predicciones de volúmen a peso. El peso de la ramas, follaje y raíces fué estimado por la modificación de las ecuaciones publicadas para el *Q. ilex* mediterráneo.

ACTIVIDAD DE PUERCOS FERALES ASOCIADA CON LA REGENERACION DE *QUERCUS AGRIFOLIA* DE LA ISLA DE SANTA CRUZ, CALIFORNIA.

Diann Peart y Duncan T. Patten.

Resumen:

La investigación comenzó en 1989 indicando que la actividad de los puercos ferales estuvo asociada positivamente con un decremento de la densidad de plántulas de especies leñosas por debajo del dosel de el encino de Costa Viva (*Quercus agrifolia*) en la Isla de Santa Cruz, California. La densidad de plántulas producidas por semillas varía significativamente entre áreas de exclusión y de control y se encontró que decrece con el impacto acumulativo del puerco en los cuadrantes controles. Una sequía de 5 años en California llevó a un abrupto declinamiento en la población de puercos ferales, pero con las recientes lluvias normales el impacto del puerco está de nuevo en aumento.

HISTORIA DE INCENDIOS EN UN BOSQUE DE PINO ENCINO MEXICANO Y UN BOSQUE MONTANA DE CONIFERAS EN GALERIA ADYACENTE EN EL SURESTE DE ARIZONA, ESTADOS UNIDOS.

Thomas W. Swetnam., Christopher H. Baisan, Anthony C. Caprio, and Peter M. Brown.

Resumen:

Troncos, tocones, y árboles cicatrizados por fuego fueron muestreados dentro de un bosque de encino-pino y un bosque de galería adyacente dominado por coníferas en el cañon de Rhyolite en el Monumento Nacional de Chiricahua. El análisis dendrocronológico de esas muestras cicatrizadas por fuego documenta un régimen de incendios caracterizado por fuegos de superficie episódicos que ocurren a intervalos de 1 a 38 años. El intervalo de incendio medio (IFM) para el área de estudio completa fue de 3.9 años para incendios que cicatrizan cualquier árbol y 13.2 años para incendios que cicatrizan al menos 25% de los árboles muestreados para el período 1620 a 1890 A.D. Basados en la posición de las heridas por fuego dentro de los anillos de los árboles y estudios recientes de fenología del cambio, esos incendios ocurren principalmente entre mayo y los últimos de julio. Las áreas bajas del cañon dominadas por vegetación de tipo bosque sostienen un reducido IFM (incendios más frecuentes) durante la última proción del siglo XIX. Este reducido IFM puede haber sido causado por cambios en las prácticas de quema de los apaches. Virtualmente no hubo actividad de incendios en las coníferas que dominan la porción central del cañon durante un período de 50 años de 1801-1851. Nosotros hipotetizamos que este hiato de 50 años en la actividad de incendios resulta de cambios en la continuidad de combustible debido inundaciones y/o eventos de flujo de desechos*. El cese del regimen episódico de incendios después de 1890 es atribuído al pastoreo por ganado y la reducción asociada a la cantidad y continuidad de combustible en superficie.

Basados en patrones modernos de fuegos encendidos por ráyos y de registro de cicatrices de incendio, el bosque de galería de encino pino en el cañon Rhyolite parece haber servido como un conducto que permite al fuego extenderse a través de gradientes de altitud. Nosotros concluimos que las fuentes de incendio importantes fueron dos bosques de pino de alta elevación en las partes altas por encima de la cabeza del cañon y en el pastizal de baja elevación y las comunidades boscosas en y debajo de la boca del cañon. La eliminación de incendios episódicos ha resultado en cambios significativos en la composición de la comunidad y estructura así como en la cantidad y distribución de madera combustible viva y muerta. Esos cambios en adición a la existencia de los límites artificiales de manejo, complicará el planeamiento e implementación de programas de manejo de incendios. Sin embargo, la perspectiva histórica ofrecida por este estudio provee una linea de base para evaluar patrones de cambio y, quizás un modelo para condiciones futuras deseadas.

ADELGAZAMIENTO DE MATORRALES DE RETONOS DE ENCINO DE EMORI: EFECTOS EN CRECIMIENTOS, RENDIMIENTOS, CICLOS DE COSECHA.

Ramzi Touchan, Duane A. Bennett and Peter F. Ffolliott.

Resumen:

Efectos de diámetro de tocón, tratamientos de adelgazamiento de matorral, y edad de los retoños al tiempo del adelgazamiento son descritos en términos de crecimientos y rendimiento para los retoños del encino de emori (*Quercus emori*) sobre un período de 5 años. El crecimiento y rendimiento de los retoños residuales depende grandemente del número de

retoños dejados después del adelgazamiento, y de la edad de esos retoños al adelgazamiento. Los efectos del diámetro del tronco fueron inconclusos. Los ciclos de cosecha para madera para leña pueden ser reducidos a través del tiempo propio para el tratamiento de adelgazamiento del soto-bosque.

SELECCION DE PLANTULAS DURANTE LA RESTAURACION DE UN BOSQUE DE ENCINO.

Thomas S. Scott y Nanette L. Pratini.

Resumen:

Un estudio fue hecho sobre la fuerza de plántulas, altura, tasa de crecimiento y número de hojas para predecir el subsiguiente crecimiento en el encino de Engelmann (*Quercus engelmannii*) un encino blanco endémico del Suroeste de California. Los datos fueron recolectados durante 4 estaciones de crecimiento de 3 experimentos en árboles plantados en el campo y el otro en recipientes de crecimiento en un invernadero. Correlaciones de rango y regresiones fueron efectuadas. Los subgrupos fueron sujetos a diferentes tratamientos, pero los tratamientos no cambiaron con el tiempo. Las alturas iniciales, tasas de crecimiento dentro del año, y el número de hojas de individuos de 1 año de edad producidos de semillas fueron pobres indicadores de la altura de plántulas y del número de hojas después de su plantación, especialmente en años posteriores. Las correlaciones entre las medidas de las plántulas de entre 1 año y el siguiente generalmente se incrementan con la edad. La variación individual en las tasas de crecimiento fue mayor dentro de los grupos de tratamiento sugiriendo la presencia de diferencias relacionadas con las bellotas a pesar de que la fuente de semillas fué de un sólo árbol para dos de los 4 experimentos. Las plántulas de invernadero, crecidas bajo condiciones uniformes, también muestran la variabilidad del primer año. Las implicaciones para la plantación de restauración incluyen plantar suficiente número de plántulas para sobrepasar la variabilidad de los individuos producidos por semilla, más que escoger plántulas basandose en su vigor aparente y demorando el aclaramiento al menos hasta el cuarto año.

CUANTIFICACION DE LOS HABITATS PARA LA VIDA SILVESTE DENTRO DE LAS ASOCIACIONES ENCINO DE GAMBEL-BOSQUE- VEGETACION DE BOSQUE EN ARIZONA.

William H. Kruse.

Resumen:

La cuantificación de diferentes formas fenológicas de crecimiento del encino de gambel dentro de la asociación de bosque - vegetación de bosque puede describir : 1) el grado de la sucesión del tipo de vegetación, 2) la cantidad de los hábitats para la vida silvestre dentro del tipo de vegetación relativo al estado sucesional, y , 3) la calidad del tipo de vegetación en relación a la diversidad de los hábitats. La evaluación de formas de crecimiento importantes desde el punto de vista sucesional del encino de gambel no solamente enfatizarán la evaluación de hábitats para la vida silvestre sino también puede mejorar el manejo ecológico.

UNA EPIDEMIA DE IPS PINONEROS EN BOSQUES DE PINON-JUNIPERO EN EL NORTE DE ARIZONA: UN CASO DE ESTUDIO.

Jill L. Wilson. and Borys M. Tkacz.

Resumen:

Una epidemia reciente de ips piñonero (escarabajo descortezador) en bosques de piñon junípero fue probablemente iniciada por una corta e intensa sequía. Una vez que la epidemia comienzó, el porcentaje de mortalidad fue mayor en las áreas donde las áreas basales eran entre 100 y 200 pies cuadrados por acre. Muérdago enano de piñon fué también encontrado en bajos niveles. El porcentaje de árboles infectados fue algo mayor en las áreas donde la mortalidad fue más grande. Los ips del piñon atacan árboles tan pequeños como de 2" de diámetro a la altura del cuello de la raíz (DRC) y tan grandes como 11" DRC. Pero parece que prefieren árboles entre 7" y 11" DRC. Los árboles en pié de alto riesgo son aquellos con áreas basales entre 100 y 200 piés cuadrados y muchos árboles con DRC's entre 7" y 11" pulgadas.

FACTORES QUE CONTROLAN LOS LIMITES INFERIORES DE ALTITUD DE LAS PLANTAS: RESPUESTA DE LOS PINOS A LA SEQUIA EN LAS MONTANAS DE CHIRICAHUA, ARIZONA.

Andrew M. Barton.

Resumen:

Seis especies de pino se encuentran en diferentes posiciones altitudinales en las Montañas de Chiricahua en el Sureste de Arizona. Sobre los rangos de las 4 especies más bajas, la humedad del suelo declina de alta a baja altitud. Tres líneas de evidencia sugieren que la resistencia a la sequía y a la sequía relativa son controladas por los límites inferiores de altitud y por la posición en al menos 4 de las especies mas bajas. Primero, en respuesta a la sequía en un invernadero, las especies de altitudes inferiores sobrevivieron más tiempo y experimentaron una menor declinación en la fotosíntesis y pérdida de potencial de agua. Segundo, cerca de sus límites inferiores de altitud, las plántulas de pino nacidas de semilla de cada especie, se encuentran en los microhábitats húmedos que rodean relativamente al azar a los microhábitats. Finalmente, las especies fueron capaces de germinar por debajo de sus límites inferiores respectivos, pero la sobrevivencia subsecuente en esas áreas fue muy poco aparente debido al estrés hídrico.

Los resultados sugieren que el estrés hídrico controla los límites inferiores de altitud al causar una alta mortalidad de los individuos jovenes nacidos de semillas, más que inhibiendo la germinación o que ejecutando a los individuos nacidos de semilla más viejos. La resistencia pronunciada a la sequía en las especies de altitudes bajas parece ser el resultado de una habilidad para evitar la caída catastrófica del potencial hídrico interno durante la sequía. Así, las posición altitudinal de estos pinos es, en parte, controlada por la habilidad de los jovenes plántulas nacidas de semilla, de mantener su balance hídrico durante sus primeras estaciones secas.

INONOTUS ANDRESONII UN HONGO DE PUDRICION DE MADERA DE LOS ARBOLES DE ENCINO EN ARIZONA.

M.L. Fairweather and Robert L. Gilbertson.

Resumen:

Inonotus andrersoni pudre los árboles en las áreas de bosques de encino a través del estado de Arizona. Las relaciones de incompatibilidad vegetativa y pudrición entre cepas aisladas de *I. andersonii* fueron investigadas in vitro. No hubo diferencias significativas (P=0.005) en las tasas de pudrición en las diferentes especies de encinos probadas (*Quercus emoryi. Q. arizonica*, *Q. gambelii*, *Q. hypoleucoides*). Sin embargo, el sicamoro, el sáuco y la pícea se fueron pudriendo a una tasa significativamente lenta. las zonas distintivas de interacción se desarrollaron entre todos las cepas aisladas por duplicado en MEA. Las zonas de interacción pigmentadas fueron también observadas en madera naturalmente infectada y podrida por *I. andersoni*. Arboles infectados individualmente pueden tener una población de genotipo diferente de *I. andersoni* exhibiendo incompatibilidad vegetativa. Observaciones de campo en Arizona indican que todas las especies de encino son susceptibles a pudrición por *I. andersoni*. Una pudrición avanzada y mortalidad se presenta en árboles viejos. las ramas podridas frecuentemente se rompen dejando un árbol vivo con cavidades o huecos que proveen habitats para anidación de aves y otras especies de vida silvestre. *Inonotus andersonii* se considera benéfico para los ecosistemas en los bosques de encino. Los aislamientos fueron infructuosos en un árbol sí la fructificación (formación de basidiocarpos) había ocurrido más de 1 o 2 años antes. Aparentemente otros microorganismos rápidamente colonizan madera podrida y expuesta.

MONITOREO DE LA RESISTENCIA ELECTRICA EN ENCINOS VIVOS DE CANON (*QUERCUS CRYSOLEPIS*) USANDO UN ZIGOMETRO.

T.E. Paysen, M.G. Narog, and M.A. Zavala

Resumen:

La zigometría fué usada para evaluar la salud del bosque de encinos vivos (*Quercus crysolepis* Liemb.) de un cañon. Midiendo los valores de resistencia eléctrica (RE) en un árbol, el zigómetro fué usado para evaluar la salud individual de los árboles en un estudio en Skinner Ridge, Bosque Nacional de San Bernardino, en el Sureste de California. La información base fue recabada de 43 árboles seleccionados al azar con el objetivo de determinar una metodología eficiente de muestreo, y para desarrollar una lectura estandar de (RE) para árboles saludables. El número de muestreos necesitados por árbol fue evaluado. Ocho puntos fueron medidos por árbol. Estos incluyen el aspecto norte, sur, este y oeste en la base y a la altura del pecho (AP) – alrededor de 15 Cms y 1.3. metros por arriba de la corona de las raíces, respectivamente. La resistencia eléctrica en los árboles, por orientación y AP, y por localización en tronco, fué generalmente similar, sin embargo, esos valores de RE varían entre los árboles. Las medidas basales fueron ligeramente menores que los valores AP, pero no significativamente así – las diferencias de media y mediana fueron alrededor de 1 Kohms. Las mediciones durante agosto de 1988 tienen un promedio de lectura de RE de 13.3 Kohms. Los valores de la mediana de RE para los 8 puntos en cada árbol estuvieron entre 12 y 14; los rangos intercuartiles estuvieron entre 2 y 5 Kohms. Aparentemente, la orientación y la localización del tronco no son significativamente diferentes para los propósitos de muestreo en encinos vivos de cañon, no dañados y saludables. Y, dos o tres réplicas de lectura del zigómetro, por árbol, pueden ser una muestra suficiente.

Selected References: The Encinal Woodlands[1]

compiled by
Peter F. Ffolliott[2] and Gerald J. Gottfried[3]

The purpose of this symposium was to examine the ecology and management of oak and associated woodlands in the southwestern United States and northern Mexico. Research to improve management of multiple values of the encinal woodlands, also referred to as the western live oak type in the Society of American Foresters classification (Ffolliott 1980) and the Madrean evergreen woodland formation by Brown and Lowe (1980), was a primary focus of the symposium.

A listing of selected references on the ecology and management of encinal woodlands is presented below to complement the papers published in this proceedings of the symposium. It was arbitrarily decided whether a reference would be placed in the ecology or management category. References listed include printed and processed reports, unpublished dissertations and theses, and typewritten reports. People interested in obtaining copies of references should request them from the author directly.

Ecology

Al-Hazzouri, A.A. 1987. Effect of soil salinity and acidity on the germination of *Quercus emoryi* and *Robinia neo-mexicana* seeds. Tucson: University of Arizona. 51 p. M.S. thesis.

Al-Hazzouri, A.A.; Ffolliott, P.F.; Bennett, D.A. 1988. Germination and seedling survival tests of oak species. In: Ffolliott, P.F.; Hasbrouck, J.D., eds. Oak woodland management: proceedings of the workshop; 1988 April 12-13; Sierra Vista, AZ. Tucson: University of Arizona, School of Renewable Natural Resources: 27-30.

Anthony, R.G. 1972. Ecological relationships between mule deer and white- tailed deer in southeastern Arizona. Tucson: University of Arizona. 123 p. Ph.D. dissertation.

Anthony, R.G.; Smith, N.S. 1977. Ecological relationships between mule deer and white-tailed deer in southeastern Arizona. Ecological Monographs. 47: 255-277.

Arriaga, L.; Diaz, S.; Mercado, C. 1992. The oak and oak-pine forests of Baja California Sur: present state and management perspectives. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (This proceedings.)

Axelrod, D.I. 1958. Evolution of the Madro-Tertiary geoflora. Botanical Review. 24: 433-509.

Axelrod, D.I. 1975. Evolution and biogeology of Madrean-Tethyan sclerophyll vegetation. Annals of the Missouri Botanical Garden. 62: 280-334.

Axelrod, D.I. 1979. Age and origin of Sonoran Desert vegetation. Occasional Pap. 132. California Academy of Science. 74 p.

Babb, G.D. 1992. Sprouting response of *Quercus arizonica* and *Quercus emoryi* following fire. Tucson: University of Arizona. 77 p. M.S. thesis.

Bahre, C.J. 1985. Wildlife in southeastern Arizona between 1859 and 1890. Desert Plants. 7: 190-194.

Baison, C.H.; Swetnam, T.W. 1990. Fire history on a desert mountain range: Rincon Mountain Wilderness, U.S.A. Canadian Journal of Forest Research. 20: 1559-1569.

Balda, R.P. 1967. Ecological relationships of the breeding birds of the Chiricahua Mountains, Arizona. Urbana: University of Illinois. 218 p. Ph.D. dissertation.

Balda, R.P. 1969. Foliage use by birds of the oak-juniper woodland and ponderosa pine forest in southeastern Arizona. Condor. 71: 399-412.

Balda, R.P. 1975. Vegetation structure and breeding bird diversity. In: Smith, D.R., tech. coord. Proceedings of the symposium on management of forest and range habitats for non-game birds. Gen. Tech. Rep. WO-1, Washington, DC: U.S. Department of Agriculture, Forest Service: 59-80.

Barton, A.M. 1991. Factors controlling the elevational positions of pines in the Chiricahua Mountains, Arizona: Drought, competition, and fire. Ann Arbor: University of Michigan. 162 p. Ph.D. dissertation.

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[1] *Bibliography prepared for symposium, Ecology and Management of Oak and Associated Woodlands: Perspectives in the Southwestern United States and Northern Mexico (Sierra Vista, AZ, April 27-30, 1992).*

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Barton, A.M. 1992. Factors controlling lower elevational limits of plants: responses of pines to drought in the Chiricahua Mountains, Arizona. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (This proceedings.)

Block, W.M.; Ganey, J.L.; Severson, K.E.; Morrison, M.L. 1992. Use of oaks by neotropical migratory birds in the Southwest. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (This proceedings.)

Bock, J.E.; Bock, C.E.; Knight, J.R. 1976. A study of the effects of grassland fires at the research ranch in southeastern Arizona. Arizona Academy of Science. 11: 49-57.

Borelli, S. 1990. Natural regeneration of oak woodlands in southeastern Arizona: A survey. Tucson: University of Arizona. 54 p. M.S. thesis.

Bowers, J.E.; McLaughlin, S.P. 1987. Flora and vegetation of the Rincon Mountains, Pima County, Arizona. Desert Plants. 8: 51-94.

Brown, D.E. 1982. Madrean evergreen woodland. In: Biotic communities of the American Southwest – United States and Mexico. Desert Plants. 4: 59-65.

Brown, D.E. 1984. Arizona's tree squirrels. Phoenix: Arizona Game and Fish Department. 114 p.

Brown, D.E.; Lowe, C.H. 1980. Biotic communities of the Southwest. Gen. Tech. Rep. RM-78. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 1 p.

Brown, D.E.; Lowe; C.H.; Pase, C.P. 1980. A digitized systematic classification for ecosystems with an illustrated summary of natural vegetation of North America. Gen. Tech. Rep. RM-73. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 93 p.

Bultman, T.L.; Faeth, S.H. 1986a. Effect of within-leaf density and leaf size on pupal weight of a leaf-miner, *Cameraria* (*Lepidoptera:Gracillariidae*). Southwestern Naturalist. 31: 201-206.

Bultman, T.L.; Faeth, S.H. 1986b. Experimental evidence for interspecific competition in a lepodopteran leaf miner. Ecology. 67: 442-448.

Bultman, T.L.; Faeth, S.H. 1986c. Leaf size selection by leaf-mining insects on *Quercus emoryi* (*Fagaceae*). Oikos. 46: 311-316.

Bultman, T.L.; Faeth, S.H. 1987. Impact of irrigation and experimental drought stress on leaf-mining insects of Emory oak. Oikos. 48: 5-11.

Bultman, T.L.; Faeth, S.H. 1988. Abundance and mortality of leaf miners on artificially shaded Emory oak. Ecological Entomology. 13: 131-142.

Camichael, R.S.; Knipe, O.D.; Pase, C.P.; Brady, W.W. 1978. Arizona chaparral: plant associations and ecology. Res. Pap. RM-202. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 16 p.

Caprio, A.C.; Zwolinski, M.J. 1992. Fire effects on Emory and Mexican blue oaks in southeastern Arizona. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (This proceedings.)

Columbus, J.T. 1988. Flora of Cooke's Range, southwestern New Mexico. Las Cruces: New Mexico State University. 80 p. M.S. thesis.

Day, G.I. 1964. An investigation of white-tailed deer (*Odocoileus virginianus couesi*) forage relationships in the Chiricahua Mountains. Tucson: University of Arizona. 101 p. M.S. thesis.

Faeth, S.H. 1985a. Host leaf selection by leaf miners: interactions among three trophic levels. Ecology. 66: 870-875.

Faeth, S.H. 1985b. Quantitative defense theory and patterns of feeding by oak insects. Oecologia. 68: 34-40.

Faeth, S.H. 1990. Aggregation of a leafminer, *Cameraria* spp. nov. (Davis): consequences and causes. Journal of Animal Ecology. 59: 569-586.

Faeth, S.H. 1991. Effect of oak leaf size on abundance, dispersion and survival of the leafminer *Cameraria* spp. (*Lepidoptera: Gracillariidae*). Environmental Entomology. 20: 196-204.

Faeth, S.H.; Bultman, T.L. 1986. Interacting effects of increased tannin levels on leaf-mining insects. Entomologia Experimentalis et Applicata. 40: 297-301.

Fairweather, M.L.; Gilbertson, R.L. 1992. *Inonotus andersonii:* a wood decay fungus of oak trees in Arizona. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (This proceedings.)

Ffolliott, P.F. 1980. Western live oak. In: Eyre, F.E., ed. Forest cover types of the United States and Canada. Washington, DC: Society of American Foresters: 118.

Gallina, S. 1981. Forest ecosystems of northwestern Mexico. In: Ffolliott, P.F.; Gallina, S., eds. Deer biology, habitat requirements, and management in western North America. Mexico: Instituto de Ecologia: 27- 56.

Gallina, S.; Ffolliott, P.F. 1983. Overstory-understory relationships: oak-pine forests of Sierra Madre Occidental, Mexico. In: Bartlett, E.T.; Betters, D.R., eds. Overstory-understory relationships in western forests. Ft. Collins: Colorado State University Experiment Station, Western Regional Research Publication 1: 19-20.

Ganey, J.L.; Balda, R.P. 1989. Distribution and habitat use of Mexican spotted owls in Arizona. Condor. 91: 355-361.

Ganey, J.L.; Duncan, R.B.; Block, W.M. 1992. Use of oak and associated woodlands by Mexican spotted owls in Arizona. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (This proceedings.)

Ganter, P.F.; Starmer, W.T.; Lachance, M.A.; Phaff, H.J. 1986. Yeast communities from host plants and associated *Drosophila* in southern Arizona: new isolations and analysis of the relative importance of hosts and vectors on community composition. Oecologia. 70: 386-392.

Gentry, H.S. 1942. Río Mayo plants: a study of the flora and vegetation of the valley of the Río Mayo. Carnegie Institute Washington Publication 527: 1-316.

Goldberg, D.E. 1982. The distribution of evergreen and deciduous trees relative to soil type: an example from the Sierra Madre, and a general model. Ecology. 63: 942-951.

Gottfried, G.J. 1992. Ecology and management of the southwestern pinyon-juniper woodlands. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (This proceedings.)

Greenwalt, L.A. 1955. Mobility of Gambel's quail (*Lophortyx gambeli gambeli*) in a desert-grassland-oak woodland in southeastern Arizona. Tucson: University of Arizona. 37 p. M.S. thesis.

Hastings, J.R. 1963. Historical changes in the vegetation of a desert region. Tucson: University of Arizona. 456 p. Ph.D. dissertation.

Hastings, J.R.; Turner, R.M. 1965. The changing mile: an ecological study of vegetation change with time in the lower mile of an arid and semi-arid region. Tucson: University of Arizona Press. 317 p.

Haworth, K. 1992. Effects of *Quercus emoryi* trees on microclimate, precipitation distribution, and herbs in a semi-arid savanna. Tucson: University of Arizona. 114 p. M.S. thesis.

Haworth, K.; McPherson, G.R. 1991. Effects of *Quercus emoryi* on precipitation distribution. Proceedings Supplement to Journal of the Arizona-Nevada Academy of Science: 21. Abstract.

Hernández C., V.M.; Hernández, F.J.; Solís González, S. 1992. Ecology of oak woodlands in the Sierra Madre Occidental of Mexico. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (This proceedings.)

Hoffmeister, D.F. 1986. Mammals of Arizona. Tucson: University of Arizona Press. 602 p.

Horton, S.P.; Mannan, R.W. 1988. Effects of prescribed fire on snags and cavity-nesting birds in southeastern Arizona USA pine forests. Wildlife Society Bulletin. 16: 37-44.

Hutto, R.L. 1985. Seasonal changes in the habitat distribution of transient insectivorous birds in southeastern Arizona: competition mediated? Auk. 102: 120-132.

Jandery, F. 1975. Chiricahua National Monument fire history. Unpublished report. 10 p. Available from: Chiricahua National Monument, USDI National Park Service, Arizona.

Kearney, T.H.; Peebles, R.H. 1964. Arizona flora. Berkeley: University of California Press. 1085 p.

Knipe, T. 1960. The javelina in Arizona. Arizona Game and Fish Department, Wildlife Bulletin 2. 96 p.

Knopp, T.B. 1959. Factors affecting the abundance and distribution of Merriam's turkey (*Meleagris gallopavo merriami*) in southeastern Arizona. Tucson: University of Arizona. 58 p. M.S. thesis.

Kosztarab, M. 1982. Observations on *Torvothrips koszarabi* (*Thysanoptera: Phlaeothripidae*) inhabiting coccoid gall (produced by *Olliffiella crisicola* on *Quercus emoryi*). Florida Entomologist. 65: 159-164.

Krausman, P.R.; Smith, N.S., eds. 1984. Deer in the Southwest: a workshop. Tucson: University of Arizona, Arizona Cooperative Wildlife Research Unit, School of Renewable Natural Resource. 131 p.

Lamb, S.H. 1989. Woody plants of the Southwest. Santa Fe, NM: Sunstone Press. 177 p.

Landres, P.B.; MacMahon, J.A. 1980. Guilds and community organization analysis of an oak woodland avifauna in Sonora, Mexico. Auk. 97: 351-365.

Landres, P.B.; MacMahon, J.A. 1983. Community organizations of arboreal birds in some oak woodlands of western North America. Ecological Monographs. 53: 183-208.

Lehr, J.H. 1978. A catalog of the flora of Arizona. Desert Botanical Garden, Phoenix, Arizona. 203 p.

Leopold, A. 1924. Grass, brush, and timber fire in southern Arizona. Journal of Forestry. 22: 1-10.

Leopold, A.S. 1960. Vegetation zones of Mexico. Ecology. 31: 507-518.

Lesueur, H. 1945. The ecology of the vegetation of Chihuahua, Mexico, north of parallel twenty-eight. Publication 4521. Austin: University of Texas.

Little, E.L., Jr. 1976. Southwestern trees: A guide to the native species of New Mexico and Arizona. Agric. Handb. 9. Washington, DC: U.S. Department of Agriculture, Forest Service. 109 p.

Lowe, C.H. 1961. Biotic communities of the sub-Mogollon region of the Inland Southwest. Journal of the Arizona Academy of Science. 2: 40-49.

Lowe, C.H. 1964. Arizona's natural environment: Landscapes and habitats. Tucson: University of Arizona Press. 136 p.

Luz, J.L.L. 1988a. *Quercus arizonica* Sargent (*Fagaceae*). Madrono. 35: 280.

Luz, J.L.L. 1988b. *Quercus oblongifolia* Torr. (*Fagaceae*). Madrono. 35: 280.

Maghini, M.T. 1990. Water use and diurnal ranges of Coues white-tailed deer. Tucson: University of Arizona. 86 p. M.S. thesis.

Maghini, M.T.; Smith, N.S. 1990. Water use and diurnal seasonal ranges of Coues white tail deer. In: Krausman, P.R.; Smith, N.S., eds. Managing wildlife in the Southwest. Phoenix: Arizona Chapter, The Wildlife Society: 21-24.

Marshall, J.T., Jr. 1957. Birds of the pine-oak woodland in southern Arizona and adjacent Mexico. Pacific Coast Avifauna. 32: 1-125.

Marshall, J.T., Jr. 1963. Fire and birds in the mountains of southeastern Arizona. Tall Timbers Fire Ecology Conference. 2: 135-141.

Martínez Islas, L. 1992. Distribution of oak in the State of Sonora, Mexico. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (This proceedings.)

McConnell, W.J.; Adams, G.F. 1974. Emory oak (*Quercus emoryi*) litter phenolics as environmental hazards for aquatic animals in southeastern Arizona. Journal of the Arizona Academy of Science. 8: 111-115.

McCranie, J.R.; Wilson, L.D. 1987. The biogeography of the herpetofauna of the pine-oak woodlands of the Sierra Madre Occidental of Mexico. Milwaukee Public Museum Contributions in Biology and Geology. 72: 1-30.

McPherson, G.R. 1992. Ecology of oak woodlands in Arizona. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (This proceedings.)

McPherson, G.R.; Drake, S. 1991. Phytosociology of oak woodlands in Arizona. Proceedings Supplement to Journal of the Arizona-Nevada Academy of Science: 20. Abstract

Medina, A.L. 1987. Woodland communities and soils of Fort Bayard, southwestern New Mexico. Journal of the Arizona-Nevada Academy of Science. 21: 99-112.

Miller, H.A.; Lamb, S.H. 1985. Oaks of North America. Happy Camp, CA: Naturegraph Publishers, Inc. 327 p.

Mogensen, H.L. 1970. Syncotyly in *Quercus arizonica*. American Journal of Botany. 57: 1207-1210.

Moir, W.H. 1979. Soil-vegetation patterns in the central Peloncillo Mountains, New Mexico. American Midland Naturalist. 102: 317-331.

Moir, W.H. 1980. Some questions about fire ecology in southwestern canyon woodlands. In: Stokes, M.A.; Dieterich, J.H., tech. coords. Proceedings of the fire history workshop; 1980 October 20-24; Tucson, AZ. Gen. Tech. Rep. RM-81. Fort Collins, CO: U.S. Department of Agriculture, Rocky Mountain Forest and Range Experiment Station: 20.

Monson, G. 1942. Notes on some birds of southeastern Arizona. Condor. 44: 222-225.

Mouat, D.A. 1974. Relationships between vegetation and terrain variables in southeastern Arizona. Tucson: University of Arizona. 230 p. Ph.D. dissertation.

Muldavin, E.H.; DeVelice, R.L. 1987. A forest habitat type classification of southern Arizona and its relationship to forests of the Sierra Madre Occidental of Mexico. In: Aldon, E.F.; Gonzáles Vicente, C.E.; Moir, W.H., tech. coords. Strategies for classification and management of native vegetation for food production in arid zones; 1987 October 12-16; Tucson, AZ. Gen. Tech. Rep. RM-150. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 24-31.

Niering, W.A.; Lowe, C.H. 1984. Vegetation of the Santa Catalina Mountains: Community types and dynamics. Vegetatio. 58: 3-28.

Nyandiga, C.O. 1991. Storage and germination of *Quercus emoryi* and *Quercus arizonica* acorns. Tucson: University of Arizona. 73 p. M.S. thesis.

Nyandiga. C.; McPherson, G.R. 1991. Germination of Emory oak in different microsites. Proceedings Supplement to Journal of the Arizona-Academy of Science: 20. Abstract.

Ortega-Rubio, A.; Romero-Schmidt, H.; Arguelles-Mendes, C. 1992. Importance of the Sierra de la Laguna woodlands for conservation of endemic species in Mexico. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (This proceedings.)

Pase, C.P. 1969. Survival of *Quercus turbinella* and *Q. emoryi* in an Arizona chaparral community. The Southwestern Naturalist. 14: 149-156.

Pérez-García, A. 1978. Ecology of the oak communities on the eastern foothills of the Sierra Madre Occidental in Chihuahua. Las Cruces: New Mexico State University. 240 p. Ph.D. dissertation.

Peterson, P.E. 1981. The effects of fuelwood cutting on hole-nesting bird populations in the oak-juniper woodland. Tucson: University of Arizona. 49 p. M.S. thesis.

Phillips, F.J. 1912. Emory oak in southern Arizona. Circular 201 Washington, DC: U.S. Department of Agriculture, Forest Service, GPO. 15 p.

Pieper, R.D. 1992. Species composition of woodland communities in the Southwest. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (This proceedings.)

Reeves, T. 1976. Vegetation and flora of Chiricahua National Monument, Cochise County, Arizona. Tucson: University of Arizona. 180 p. M.S. thesis.

Robert, M.F. 1977. Essai sur l'evolution de la forest de coniferes de la Sierra Madre Occidentale (Mexico). Revue Forestiere Francaise. 29: 407-416.

Roseberry, R.D.; Dole, N.E., Jr. 1939. The vegetation type survey of Chiricahua National Monument. San Francisco, CA: U.S. Department of Interior. 42 p.

Sanchini, P.J. 1981. Population structure and fecundity patterns in *Quercus emoryi* and *Quercus arizonica*. Boulder: University of Colorado. 149 p. Ph.D. dissertation.

Sayers, S.J. 1974. Natural vegetation of state, private, and Bureau of Land Management lands in Arizona. Arizona Land Marks. 4: 1-45.

Schmutz, E.M. 1978. Classified bibliography of native plants of Arizona, USA. Coden. 160 p.

Severson, K.E. 1986. Woody plant reestablishment in modified pinyon-juniper woodlands, New Mexico, USA. Journal of Range Management. 39: 438-442.

Smith, A.P. 1908. Some data and records from the Whetston Mountains, Arizona. Condor. 10: 75-78.

Smith, N.S.; Anthony, R.G. 1992. Coues white-tailed deer and the oak woodlands. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern

United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (This proceedings.)

Swank, W.G. 1958. The mule deer in Arizona chaparral. Arizona Game and Fish Department, Wildlife Bulletin 3. 109 p.

Swetnam, T.W.; Baisan, C.H.; Brown, P.M.; Caprio, A.C. 1989. Fire history of Rhyolite Canyon, Chiricahua National Monument. Tech. Rep. 32. AZ: USDI National Park Service. 47 p.

Swetnam, T.W.; Baisan, C.H.; Caprio, A.C.; Brown, P.M. 1992. Fire history in a Mexican oak-pine woodland and adjacent montane conifer gallery forest in southeastern Arizona. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (This proceedings.)

Swetnam, T.W.; Baisan, C.H.; Caprio, A.C.; McCord, V.A.S.; Brown, P.M. 1991. Fire and flood in a canyon woodland: the effects of floods and debris flows on the past fire regime of Rhyolite Canyon, Chiricahua National Monument. Final report. Available from: USDI National Park Service, Arizona or Laboratory of Tree-ring Research, University of Arizona, Tucson. 51 p.

Truett, J.C. 1971. Ecology of the desert mule deer (*Odocoileus hemionus crooki* Mearns) in southern Arizona. Tucson: University of Arizona. 64 p. Ph.D. dissertation.

Tucker, J.M. 1963. Studies of the *Quercus undulata* complex: III. The contribution of *Quercus arizonica*. American Journal of Botany. 50: 699-708.

Wagner, W.L. 1977. Floristic affinities of the Animas Mountains, southwestern New Mexico. Albuquerque: University of New Mexico. 82 p.

Wallmo, O.C. 1955. Vegetation of the Huachuca Mountains, Arizona. The American Midland Naturalist. 54: 466-480.

Welch, J.M. 1960. A study of the seasonal movements of white-tailed deer (*Odocoileus virginianus couesi*) in the Cave Creek Basin of the Chiricahua Mountains. Tucson: University of Arizona. 79 p. M.S. thesis.

Wentworth, T.R. 1985. Vegetation on limestone in the Huachuca Mountains, Arizona, USA. Southwestern Naturalist. 30: 385-396.

Whittaker, R.H.; Niering, W.A. 1964. Vegetation of the Santa Catalina Mountains, Arizona: I. Ecological classification and distribution of species. Journal of the Arizona Academy of Science. 3: 9-34.

Whittaker, R.H.; Niering, W.A. 1965. Vegetation of the Santa Catalina Mountains, Arizona: II. A gradient analysis of the south slope. Ecology. 46: 429-452.

Management

Allen, L. 1988. Range management. In: Ffolliott, P.F.; Hasbrouck, J.D., eds. Oak woodland management: proceedings of the workshop; 1988 April 12-13; Sierra Vista, AZ. Tucson: University of Arizona, School of Renewable Natural Resources: 75-76.

Allen, L.S. 1989a. Roots of the Arizona livestock industry. Rangelands. 11: 9-13.

Allen, L.S. 1989b. Livestock and the Coronado National Forest. Rangelands. 11: 14-20.

Allen, L.S. 1992. Livestock-wildlife coordination in the encinal oak woodlands: Coronado National Forest. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (This proceedings.)

Bahre, C.J. 1977. Land-use history of the Research Ranch, Elgin, Arizona. Supplement 2 to Journal of the Arizona Academy of Science 12: 1-32.

Bahre, C.J. 1991. A legacy of change: historic human impact on vegetation of the Arizona borderlands. Tucson: University of Arizona Press. 231 p.

Bahre, C.J.; Hutchinson, C.F. 1985. The impact of historic fuelwood cutting on the semidesert woodlands of southeastern Arizona. Journal of Forest History. 29: 175-186.

Bennett, D.A. 1985. Evaluation of growing media for Arizona white oak seeds. Tucson: University of Arizona, School of Renewable Natural Resources, College of Agriculture. 8 p.

Bennett, D.A. 1986. Fuelwood harvesting in southeastern Arizona. Tucson: University of Arizona, School of Renewable Natural Resources, College of Agriculture. 10 p.

Bennett, D.A. 1988. Effects of coppice treatment on Emory oak. In: Ffolliott, P.F.; Hasbrouck, J.D., eds. Oak woodland management: proceedings of the workshop; 1988 April 12-13; Sierra Vista, AZ. Tucson, University of Arizona, School of Renewable Natural Resources: 31-37.

Bennett, D.A. 1990. First-year effects of thinning coppice on *Quercus emoryi* in southeastern Arizona. Tucson: University of Arizona. 50 p. M.S. thesis.

Bennett, D.A. 1992. Fuelwood extraction in southeast Arizona. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (This proceedings.)

Bennett, D.A.; Nelson, G. 1988. Fuelwood sale operation. In: Ffolliott, P.F.; Hasbrouck, J.D., eds. Oak woodland management: proceedings of the workshop; 1988 April 12-13; Sierra Vista, AZ. Tucson: University of Arizona, School of Renewable Natural Resources: 79-82.

Bennett, P.S.; Kunzmann, M.R. 1992. The applicability of generalized fire prescriptions to burning of Madrean evergreen forest and woodland. Journal of the Arizona-Nevada Academy of Science. 24-25: 79-84.

Born, J.D.; Chojnacky, D.C. 1985. Woodland tree volume estimation: a visual segmentation technique. Res. Pap. INT-344. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 16 p.

Brown, R.L. 1982. Effects of livestock grazing on Mearn's quail in southeastern Arizona. Journal of Range Management. 35: 727-732.

Callison, J.C. 1988. Site quality indices for Emory oak. In: Ffolliott, P.F.; Hasbrouck, J.D., eds. Oak woodland management: proceedings of the workshop; 1988 April 12-13; Sierra Vista, AZ. Tucson: University of Arizona, School of Renewable Natural Resources, University of Arizona: 39-43.

Callison, J.C. 1989. Site quality indices for the Emory oak woodlands of southeastern Arizona. Tucson: University of Arizona. 38 p. Ph.D. dissertation.

Chojnacky, D.C. 1988a. Juniper, pinyon, oak, and mesquite volume equations for Arizona. Res. Pap. INT-391. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 11 p.

Chojnacky, D.C. 1988b. Woodland volume equations for Arizona Fort Apache and San Carlos Indian Reservations. Res. Note INT-379. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 7 p.

Chojnacky, D.C. 1992. Estimating volume and biomass for dryland oak species. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (These proceedings.)

Claveran A., R.; Sánchez B., C.; Paulin W., S.; de Alba A., A. 1987. Manejo integrado de la cuenca hidrologic "El Plateado." In: Aldon, E.F.; Gonzáles Vicente, C.E.; Moir, W.H., tech. coords. Strategies for classification and management of native vegetation for food production in arid zones; 1987 October 12-16; Tucson, AZ. Gen. Tech. Rep. RM-150. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 225-231.

Collins, D.C. 1989. Timberland and woodland resources outside National Forests in Arizona, 1985. Res. Bull. INT-66. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 61 p.

Conner, G.W. 1988. Soil considerations. In: Ffolliott, P.F.; Hasbrouck, J.D., eds. Oak woodland management: proceedings of the workshop; 1988 April 12-13; Sierra Vista, AZ. Tucson: University of Arizona, School of Renewable Natural Resources: 71.

Connor, R.C.; Born, J.D.; Green, A.W.; O'Brien, R.A. 1990. Forest resources in Arizona. Res. Bull. INT-69. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 92 p.

Deecken, T. 1988. Wildlife management. In: Ffolliott, P.F.; Hasbrouck, J.D., eds. Oak woodland management: proceedings of the workshop; 1988 April 12-13; Sierra Vista, AZ. Tucson: University of Arizona, School of Renewable Natural Resources: 77-78.

Duenez, R.L., Jr. 1987. Oak fuelwood volume estimation in the Huachuca Mountains of Arizona. Tucson: University of Arizona. 51 p. M.S. thesis.

Ffolliott, P.F. 1988a. Characteristics of the oak woodlands. In: Ffolliott, P.F.; Hasbrouck, J.D., eds. Oak woodland management: proceedings of the workshop; 1988 April 12-13; Sierra Vista, AZ. Tucson: University of Arizona, School of Renewable Natural Resource: 1-6.

Ffolliott, P.F. 1988b. Management opportunities in the oak woodlands. In: Ffolliott, P.F.; Hasbrouck, J.D., eds. Oak woodlands management: proceedings of the workshop; 1988 April 12-13; Sierra Vista, AZ. Tucson: University of Arizona, School of Renewable Natural Resources: 83-88.

Ffolliott, P.F. 1989. Arid zone forestry program: state of knowledge and experience in North America. Tech. Bull. 264. Tucson: University of Arizona, Arizona Agricultural Experiment Station. 80 p.

Ffolliott, P.F. 1990. Ecología, manejo y utilizacion de arboles maderables. Boletín Tecnico 1. Convenio Internacional de Entendimiento. 80 p.

Ffolliott, P.F. 1991. Manejo forestal en zonas áridas y semi-áridas para conservación y un desarrollo sostenido. Boletín Técnico 5. Convenio Internacional de Entendimiento. 122 p.

Ffolliott, P.F. 1992. Multiple values of woodlands in the southwestern United States and northern Mexico. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: Perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (These proceedings.)

Ffolliott, P.E.; Gottfried, G.J. 1992. Growth, yield, and utilization of oak woodlands in the southwestern United States. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins. CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (These proceedings.)

Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A. 1992. Research and management needs in the woodlands of the southwestern United States and northern Mexico. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (These proceedings.)

Ffolliott, P.F.; Guertin, D.P. 1987. Opportunities for multiple use values in the encinal oak woodlands of North America. In: Aldon, E.F.; Gonzáles Vicente, C.E.; Moir, W.H., tech. coords. Strategies for classification of natural vegetation for food production in arid zones; 1987 October 12-16; Tucson, AZ. Gen. Tech. Rep. RM-150. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 182-189.

Ffolliott, P.F.; Guertin, D.P. 1988. Simulation of growth and yield in oak woodlands for management purposes. In: Ffolliott, P.F.; Hasbrouck, J.D., eds. Oak woodland management: proceedings of the workshop; 1988 April 12-13; Sierra Vista, AZ. Tucson, University of Arizona, School of Renewable Natural Resources: 19-25.

Ffolliott, P.F.; Hasbrouck, J.D., eds. 1988. Oak woodland management: proceedings of the workshop; 1988 April 12-13; Sierra Vista, AZ. Tucson, University of Arizona, School of Renewable Natural Resources. 88 p.

Ffolliott, P.F.; Lefevre, R. 1988. Future research needs in the oak woodlands. In: Ffolliott, P.F.; Hasbrouck, J.D., eds. Oak woodland management: proceedings of the workshop; 1988 April 12-13; Sierra Vista, AZ. Tucson: University of Arizona, School of Renewable Natural Resources: 45-46.

Ffolliott, P.F.; Rasmussen, W.O.; Guertin, D.P. 1988. STAND: An interactive model to simulate the growth and yield of woodlands in the Southwest. In: Ek, A.R.; Shifley, S.R.; Burk, T.E., eds. Forest growth modelling and prediction: Proceedings of the IUFRO conference. Gen. Tech. Rep. NC-120. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 968-975.

Ffolliott, P.F.; Rasmussen, W.O.; Patterson, J.G. 1980. Biomass energy: Potentials in Arizona. Biosources Digest. 2: 240-247.

Ffolliott, P.F.; Rasmussen, W.O.; Warfield, T.K.; Borland, D. S. 1979. Supply, demand, and economics of fuelwood markets in selected population centers of Arizona. Arizona Land Marks. 9: 1-74.

Fowler, W.P. 1990. Variable-density yield tables for Emory oak of southeastern Arizona. Tucson: University of Arizona. 73 p. Ph.D. dissertation.

Fowler, W.P.; Ffolliott, P.F. 1992. Structure of a variable - density yield table for Emory oak. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (These proceedings.)

Gallaher, J.E. 1988. Visual management considerations applicable to fuelwood harvesting in the oak woodlands. In: Ffolliott, P.F.; Hasbrouck, J.D., eds. Oak woodland management: proceedings of the workshop; 1988 April 12-13; Sierra Vista, AZ. Tucson, University of Arizona, School of Renewable Natural Resources: 63-66.

Hernández C., V.M.; Hernández, F.J.; Solís González, S. 1992. Management and silvicultural practices applied to pine-oak forests in Durango, Mexico. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (These proceedings.)

Huber, D.W. 1992. Utilization of hardwoods, fuelwood, and special forest products in California, Arizona, and New Mexico. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (These proceedings.)

Klemmedson, J.O.; Smith, E.L. 1979. Forest soils and land use. In: Youngberg, C.T., ed. Vegetation-soil relationships of forests, woodlands and grasslands of Arizona and New Mexico. Fort Collins, CO: Department of Forest and Wood Sciences, Colorado State University: 42-67.

Krausman, P.R.; Smith, N.S., eds. 1990. Managing wildlife in the Southwest: Proceedings of the symposium. Phoenix: Arizona Chapter, The Wildlife Society. 262 p.

Lefevre, R. 1988. Watershed management. In: Ffolliott, P.F.; Hasbrouck, J.D., eds. Oak woodland management: proceedings of the workshop; 1988 April 12-13; Sierra Vista, AZ. Tucson: University of Arizona, School of Renewable Natural Resources: 73-74.

Long, G.; Lefevre, R. 1988. Implementation of the integrated resources management system (IRM) with a geographic information system (GIS). In: Ffolliott, P.F.; Hasbrouck, J.D., eds. Oak woodland management: proceedings of the workshop; 1988 April 12-13; Sierra Vista, AZ. Tucson: University of Arizona, School of Renewable Natural Resources: 53-61.

Lopes, V.L.; Ffolliott, P.F. 1992. Hydrology and watershed management of oak woodlands in southeastern Arizona. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (These proceedings.)

Maingi, J.K. 1992. Specific gravity and estimated physical properties of Emory oak in southeastern Arizona. Tucson: University of Arizona. 44 p. M.S. thesis.

Maingi, J.K.; Ffolliott, P.F. 1992. Specific gravity and estimated physical properties of Emory oak in southeastern Arizona. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (These proceedings.)

Mass Porras, J. 1977. Los encinos como fuente potencial de madera para celulosa y papel en Mexico. Ciencia Forestal. 2: 39-58.

McClaran, M.P.; Allen, L.S.; Ruyle, G.B. 1992. Livestock production and grazing management in the encinal oak woodlands of Arizona. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (These proceedings.)

McLain, W.H. 1988. Arizona's 1984 fuelwood harvest. Res. Bull. INT-57. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 8 p.

McMurtray, M. 1978. Inventory of oak species on the Santa Catalina Mountains, Arizona. Tucson: University of Arizona, School of Renewable Natural Resources, College of Agriculture. 5 p.

Meyer, J.W. 1988. First year coppice regeneration of *Quercus emoryi* and *Quercus arizonica* in the Huachuca Mountains of Arizona. Tucson: University of Arizona. 51 p. M.S. thesis.

Muldavin, E.; Ronco, F., Jr.; Aldon, E.F. 1990. Consolidated stand tables and biodiversity data base for southwestern forest habitat types. Gen. Tech. Rep. RM-190. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 51 p.

Patterson, J.G. 1980. Potential energy equivalents of vegetation types in Arizona. Tucson: University of Arizona. 136 p. M.S. thesis.

Propper, J.G. 1992. Recreation, aesthetics, cultural resources. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and

AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (These proceedings.)

Sharman, J.W. 1992. Management effects on structural diversity in oak woodlands of southeastern Arizona. Tucson: University of Arizona. 40 p. M.S. thesis.

Sharman, J.W.; Ffolliott, P.F. 1992. Structural diversity in oak woodlands of southeastern Arizona. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (These proceedings.)

Schelhas, J.W., Jr. 1979. The role of natural amenities in the wilderness recreation experience in the Chiricahua Mountains. Tucson: University of Arizona. 93 p. M.S. thesis.

Schlund, S.S. 1982. Potential energy equivalents of biomass residues from land management practices in Arizona. Tucson: University of Arizona. 50 p. M.S. thesis.

Spoerl, P.M.; Farrell, M.M. 1988. Cultural resources and oak woodland areas. In: Ffolliott, P.F.; Hasbrouck, J.D., eds. Oak woodland management: proceedings of the workshop; 1988 April 12-13; Sierra Vista, AZ. Tucson: University of Arizona, School of Renewable Natural Resources: 67-69.

Tolisano, J.A. 1984. Contributions of woody biomass to energy requirements in Arizona. Tucson: University of Arizona. 62 p. M.S. thesis.

Tongvichit, B. 1987. A standard volume table for Emory oak in southeastern Arizona. Tucson: University of Arizona. 23 p. M.S. professional paper.

Tongvichit, B.; Ffolliott, P.F. 1988. Emory oak volume table. In: Ffolliott, P.F.; Hasbrouck, J.D., eds. Oak woodland management: proceedings of the workshop; 1988 April 12-13; Sierra Vista, AZ. Tucson: University of Arizona, School of Renewable Natural Resources: 7-10.

woodlands in southeastern Arizona. Tucson: University of Arizona. 36 p. M.S. thesis.

Touchan, R. 1988. Growth and yield of Emory oak. In: Ffolliott, P.F.; Hasbrouck, J.D., eds. Oak woodland management: proceedings of the workshop; 1988 April 12-13; Sierra Vista, AZ. Tucson: University of Arizona, School of Renewable Natural Resources: 11-18.

Touchan, R. 1991. Effects of coppice thinning on growth and yield of Emory oak in southeastern Arizona. Tucson: University of Arizona. 130 p. Ph.D. dissertation.

Touchan, R.; Bennett, D.A.; Ffolliott, P.F. 1992. Coppice thinning of Emory oak sprouts: effects on growth, yield, and harvesting cycles. In: Ffolliott, P.F.; Gottfried, G.J.; Bennett, D.A.; Hernández C., V.M.; Ortega-Rubio, A.; Hamre, R.H., tech. coords. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico; 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. (This proceedings.)

Turner, J. 1988. Land use planning. In: Ffolliott, P.F.; Hasbrouck, J.D., eds. Oak woodland management: proceedings of the workshop; 1988 April 12-13; Sierra Vista, AZ. Tucson: University of Arizona, School of Renewable Natural Resources: 47-51.

Van Hooser, D.D. 1990. Timberland and woodland resources outside National Forests in New Mexico, 1987. Res. Bull. INT-68. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 72 p.

Voorhies, G.; Huntsberger, T.G. 1983. Heat of combustion of ponderosa pine and selected species indigenous to the Rocky Mountain region. Arizona Forestry Notes 19. 14 p.

Yacouba, D. 1987. Comparison of oak tree stand tables developed from plot sampling and point sampling in the San Rafael Valley, southeastern Arizona. Tucson: University of Arizona, School of Renewable Natural Resources, College of Agriculture. 25 p.

Zanga, A. 1990. Sampling efficiency evaluation in Emory oak woodlands of southeastern Arizona. Tucson: University of Arizona. 52 p. M.S. thesis.

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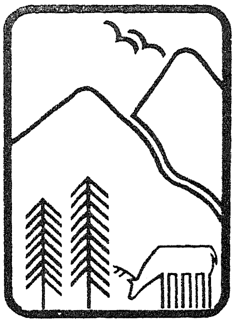
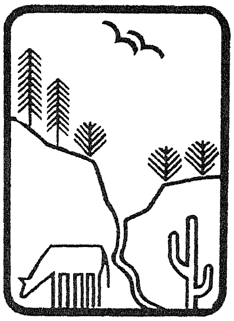


Rocky Mountains



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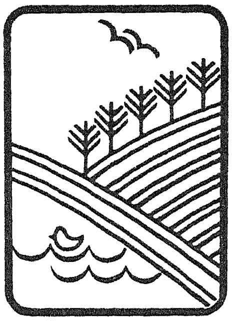

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect Rd., Fort Collins, CO 80526